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Morphological Variation in ´Djalmabatista´ (Diptera: Chironomidae) Associated with Coal Strip Mine Ponds

Tennessee Valley Authority, Muscle Shoals, AL

Prepared for

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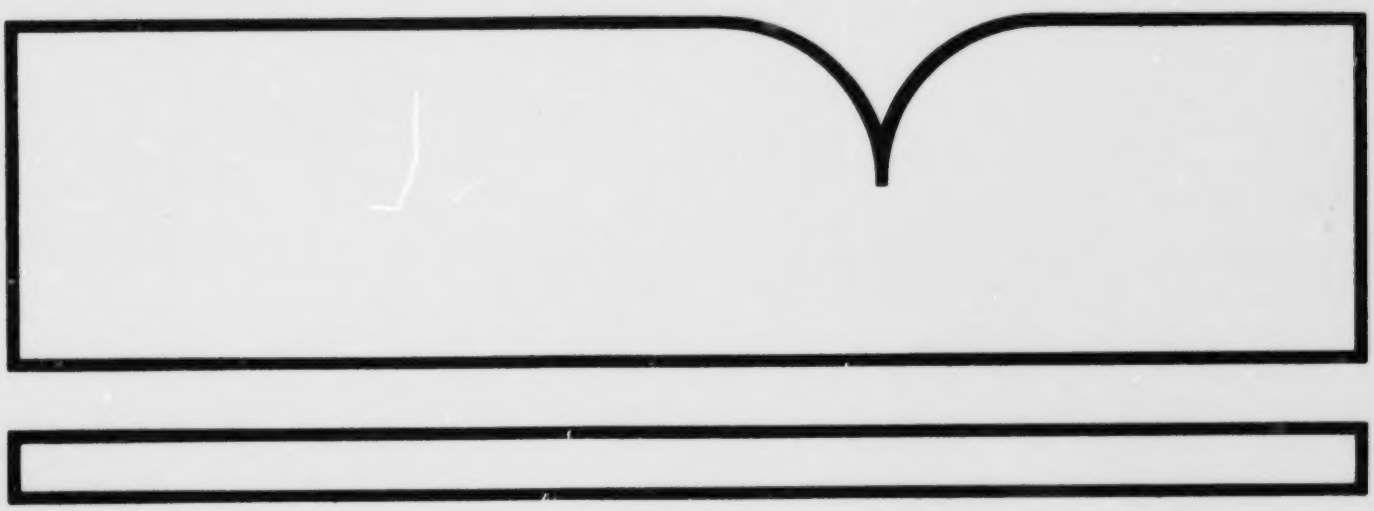

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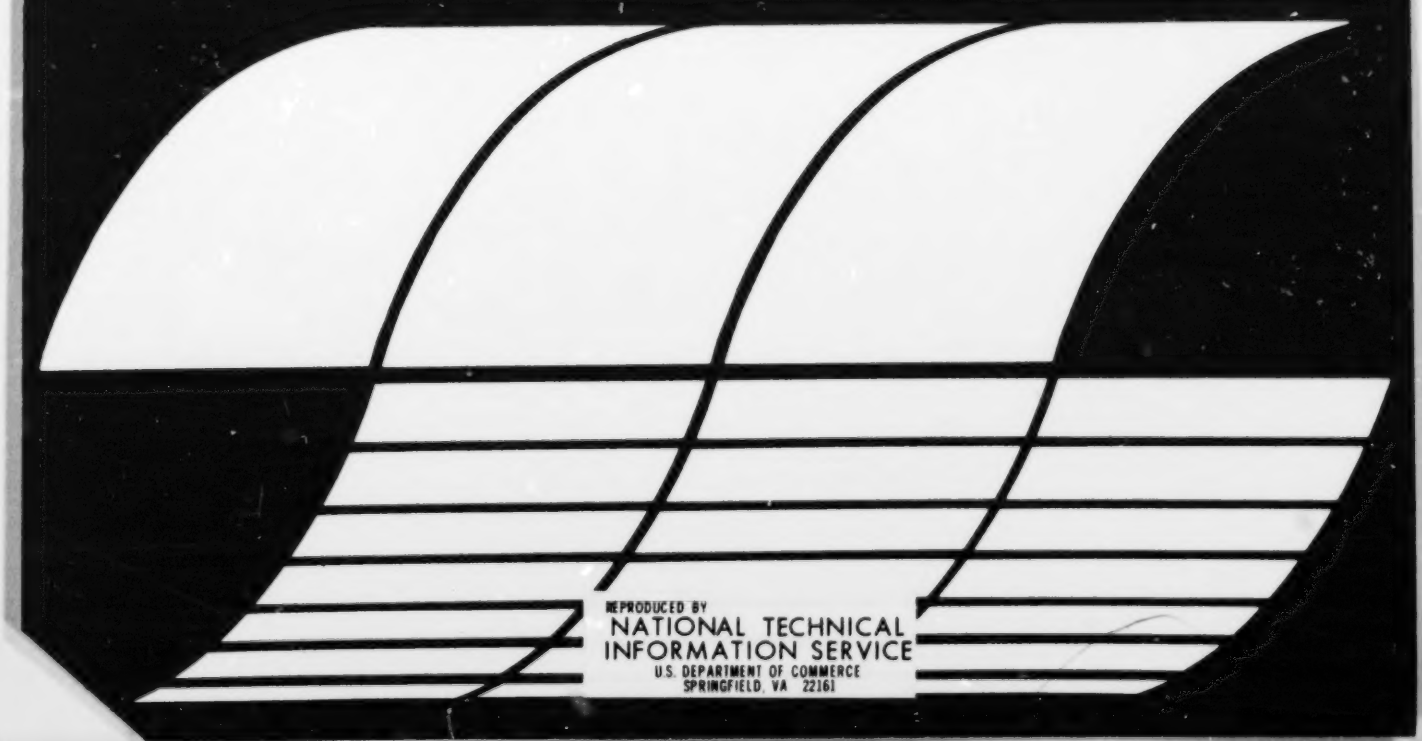

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by

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FOREWORD

Environmental disturbance by strip mining has prompted numerous studies to evaluate the effects of mining practices on physicochemical and biological components of the environment. Various approaches, such as faunal composition, diversity index, and toxicity tests have been used to detect and characterize biotic changes. However, investigations of the responses of individual organisms to strip mining disturbance are almost nonexistent.

This study attempts to describe and evaluate the effect of coal strip mine pond habitats on the morphology of an aquatic insect which quickly inhabits such ponds after their formation. This type of approach has the potential to further delineate impacts on aquatic organisms and to identify useful biotic indicators of water quality.

ABSTRACT

Larvae of Djalmabatista pulcher (Johannsen) possessing abnormally-shaped ligulas were found in abandoned coal strip mine ponds near Brilliant, Alabama. Of the total 1,472 larvae examined, 50 possessed an abnormal ligula (3.4%), a frequency greater than previously reported for chironomids. Abnormalities were found in larval instars II, III, and IV. Based on monthly samples from June to October 1978, the combined frequency of abnormalities in three strip mine ponds (3.04%) was not significantly different from the frequency at the unmined reference site, Marion County Lake (1.85%) ($P = 0.36$). The frequencies of abnormalities were not significantly correlated with any measured water quality or biological parameter related to strip mine activity.

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INTRODUCTION

The future reliance on coal as a major energy source in the United States will bring about an increase in mining activity. Approximately half of the coal now being mined is extracted by strip mining, a method which results in gross environmental change. Uncontrolled strip mining practices in the past augmented environmental concerns that led to the enactment of Public Law 95-87, entitled "Surface Mining Control and Reclamation Act of 1977," which requires reclamation of stripped land back to the approximate original contour (with exceptions for certain types of ensuing land use). Prior to enactment of this legislation, the major impact of strip mining was the alteration of natural surface contours and subsequent abandonment of mined land. Consequently, large tracts of nearly barren land punctuated with small lakes, spoil banks, and highwalls still exist.

The small lakes and ponds created in unreclaimed strip mine areas constitute a unique type of aquatic ecosystem. They may be colonized by diverse forms of aquatic life and visited by many species of wildlife. The weathering and erosion of the surrounding, exposed rock and soil dictates the physicochemical conditions of the ponds. Great fluctuations in water quality and sedimentation usually occur. Saline enrichment of these strip mine ponds can cause unusually high anion and cation concentrations, suspended and dissolved solid concentrations, conductivity, and calcium-magnesium hardness. In addition, organisms within the influence of strip mine drainage may be adversely affected. Studies of invertebrate fauna in strip mine areas usually report changes in community structure, such as species or population reductions or lowered diversity index values.[1,2,3,4,5,6] Furthermore, most studies have been conducted on streams.

One of the first and ecologically most important groups of aquatic macroinvertebrates to colonize strip mine ponds is the Chironomidae (Diptera), commonly known as midges. These small, diverse insects spend the larval stage in the water and constitute an integral part of the food web. The larval diet consists of detritus, algae, planktonic crustaceans, oligochaetes, and other chironomid larvae, depending on the species. The larvae are preyed upon by a large number of aquatic insects, fish, and other aquatic vertebrates and thus are important in the aquatic food web.

While examining chironomid larvae collected by TVA biologists from coal strip mine ponds located near Brilliant, Alabama, we observed some unusual mouthparts in a genus initially identified as Procladius. The ligula (a fork-like structure used for feeding) of this genus characteristically has five black teeth, of which the median tooth is the smallest and the first laterals are slightly smaller than the outer laterals.[7] Larvae were collected from one of the ponds on September 28, 1976; out of the 122 larvae, 118 had a ligula with fewer teeth than typical Procladius and/or teeth that appeared asymmetrical or deformed. The most common arrangement, found in 108 larvae (88.5%), was four symmetrical teeth. Identification of species within Procladius is possible only with adult males. Adults we obtained from larvae with four ligular teeth were Procladius pulcher (Johannsen), of which the immature stages were previously unknown. This species differs significantly from other Procladius species in larval and pupal characteristics, and subsequently has been placed in the genus Djalmabatista.[8]

The discovery of the larva of Djalmabatista pulcher revealed that those larvae initially examined having four symmetrical ligular teeth were not abnormal Procladius larvae. However, the D. pulcher larvae with other ligular variations, such as three, five, or six teeth, some asymmetrical, still comprised 11.5 percent of the first collection. This percentage of abnormal individuals seemed to be higher than expected for a natural population and therefore warranted investigation based on the assumption that strip-mine water quality was the most likely cause of the abnormalities and thus there were implications to the food chain.

The objectives of this study were to (1) determine the incidence of ligula abnormalities in Djalmabatista pulcher larvae inhabiting strip mine ponds near Brilliant, Alabama, and to compare this incidence with that of a population outside the influence of strip mining, (2) describe the variation found, and (3) if the incidence warrants, investigate possible factors causing the abnormalities.

Morphological deformities in chironomid larvae have been described by Brinkhurst, et al.[9], Saether[10], and Hamilton and Saether[11]. Beck (personal communication) has seen aberrant larvae of several genera, including Procladius from areas near fossil-fuel generating plants. Blaylock[12,13,14] discovered that low-level radiation induces chromosomal inversions and deletions in two species of Chironomus. Wulker[15] and Aagaard[16] found morphological changes in adult chironomids that were parasitized by mermithid nematodes in the larval stage.

CONCLUSIONS

The water quality data and sedimentation problems indicate that the strip mine ponds studied constitute harsher environments, in general, than the reference lakes. Relative population density of the midge, Djalmabatista pulcher, in Marion County Lake was greater than the densities in the three strip mine ponds sampled. Furthermore, larvae from Marion County Lake were slightly larger on the average than larvae from the strip mine ponds.

The normal configuration of the ligula in D. pulcher is four symmetrical black teeth. The eight types of abnormal ligulas found comprised a higher incidence (3.4%) than previously reported in any species of chironomid. However, the combined incidence of abnormalities in our three strip mine ponds (3.04%, n = 395) was not significantly different from the incidence in Marion County Lake (1.85%, n = 542). Therefore, populations of D. pulcher inhabiting abandoned strip mine ponds appear not to be adversely affected morphologically. Because of the similar frequencies of abnormalities in the samples, no attempts to induce abnormalities in the laboratory were made.

The lack of information on the incidence of ligula abnormalities in populations of D. pulcher outside our study area precludes comparison with our reference lake. Some combination of factors common to the study area in northern Alabama may be responsible for the similar frequencies in the strip mine ponds and Marion County Lake.

RECOMMENDATIONS

In view of the similar frequencies of ligula abnormalities in larval populations of Djalmabatista pulcher inhabiting the study ponds and the reference lake, attempts to induce abnormalities in order to pinpoint causative factors are not recommended. Therefore, we recommend that the project be terminated. However, it is desirable that further study be directed at other populations of D. pulcher and perhaps other aquatic insects outside the area of study so that the natural incidence of abnormalities can be defined. In addition, biotic indicators of water quality may be identified.

EXPERIMENTAL PROCEDURES

Description of Study Area

1. Marion County

All of the field investigations were conducted in Marion County located in northwest Alabama (Figure 1). The topography of the county is irregular, with low rounded hills in the south and southwest, and rough, broken almost mountainous areas in the central and northern parts. Elevations in the county range from about 120 to 275 m above mean sea level.

Sedimentary rock formations that crop out in the county are of the Mississippian, Pennsylvanian, Cretaceous, or Quaternary age. Mineral resources consist chiefly of coal, clay, sand, and gravel. There are five coal seams of known economic value, the major seams being the Bear Creek, Black Creek, and Jefferson.

Summers in Marion County are long and warm, and winters are short and mild. The mean annual temperature is about 17°C, and the mean annual precipitation is about 135 cm. Weekly mean maximum and minimum temperatures for the Hamilton area in 1978 are shown in Figure 2.

2. Brilliant Strip Mine Area

The Brilliant strip mine area is located in the southeast part of the county. The mining area is surrounded by second and third growth pine and deciduous forest. Sandstone predominates below a thin layer of topsoil. The Black Creek coal seam that is mined in the area varies in thickness from 46 to 80 cm with a sandstone-shale overburden of 17 to 27 m.

Numerous ponds were formed by the strip mining operation, which began in the area in 1965. These abandoned ponds, ranging in age from 3 to 12 years, are surrounded by spoil banks and/or high walls, allowing for excessive erosion during periods of heavy rainfall. Water level in the ponds is maintained by subterranean seepage and rainfall.

Methods

Six strip mine ponds of three age classes (2-3, 6-7, and 11-12 years) located in the Brilliant strip mine area (Figure 3) were chosen on the basis of accessibility, size, and the presence of Djalmabatista larvae. Buttahatchee Lake, located 7 km north of the strip mine area, was chosen initially as a reference lake. Larger in size than any of the ponds, Buttahatchee Lake is actually a reservoir created by the blockage of the Buttahatchee River, which has a constant year-round flow. Marion County Lake, located 24 km west of the strip mine ponds, was added as a second reference lake in June 1978.

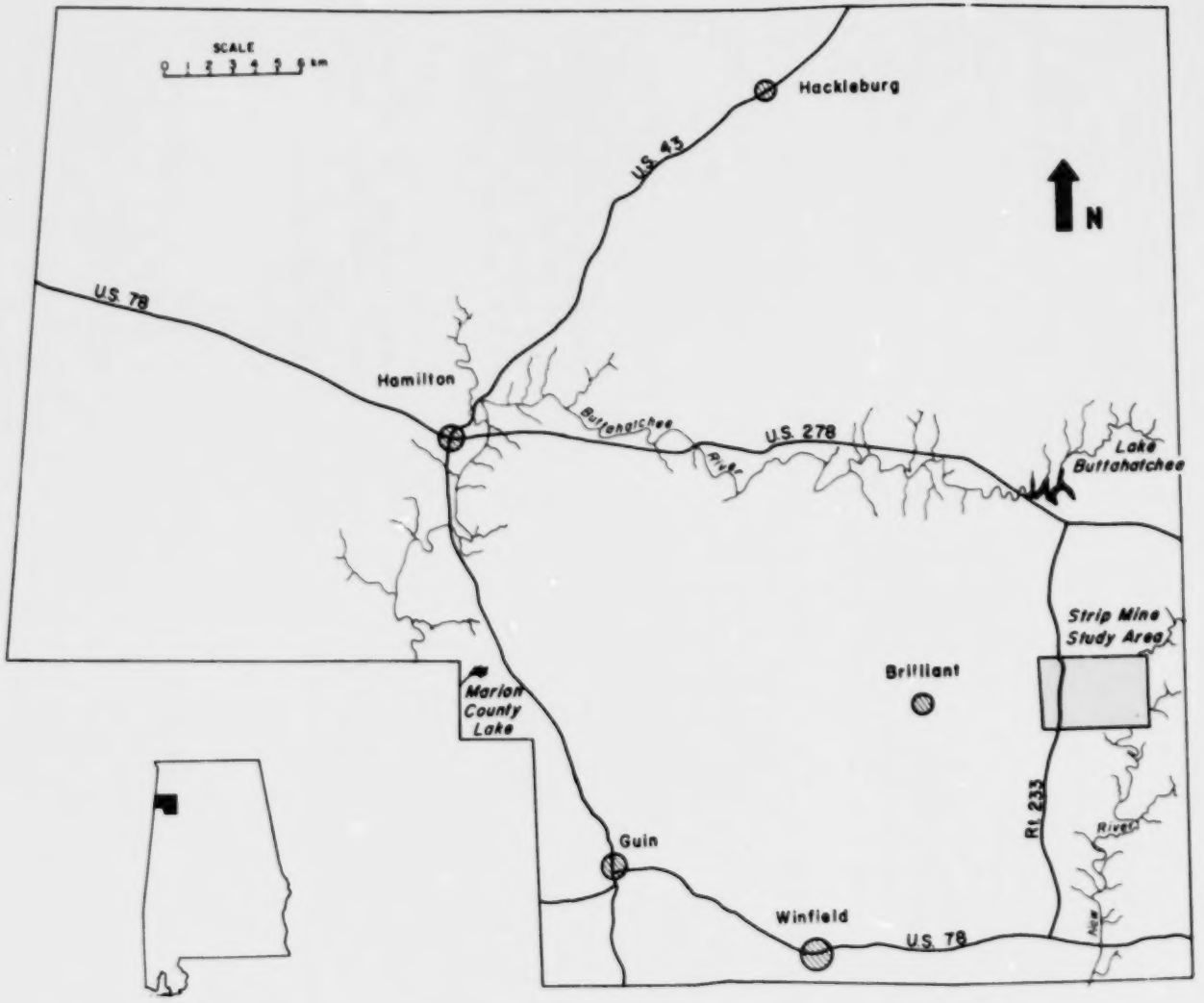

Figure 1. Map of Marion County, Alabama, showing location of Buttahatchee Lake, Marion County Lake, and the coal strip mine area east of Brilliant in which the study ponds are located (enlarged in Figure 3).

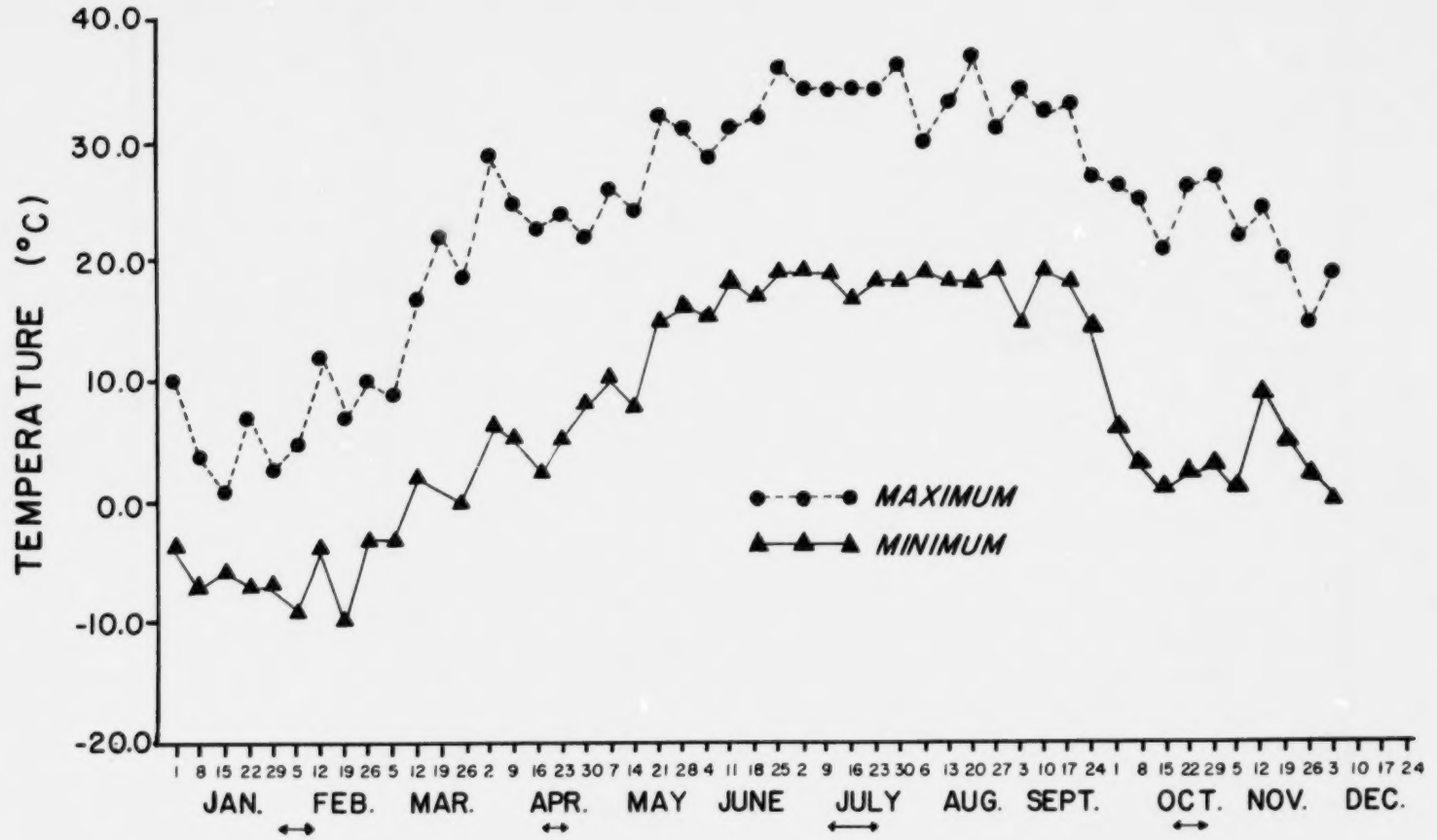

Figure 2. Weekly mean maximum and minimum air temperatures recorded at the Hamilton Airport, Marion County, 1978.

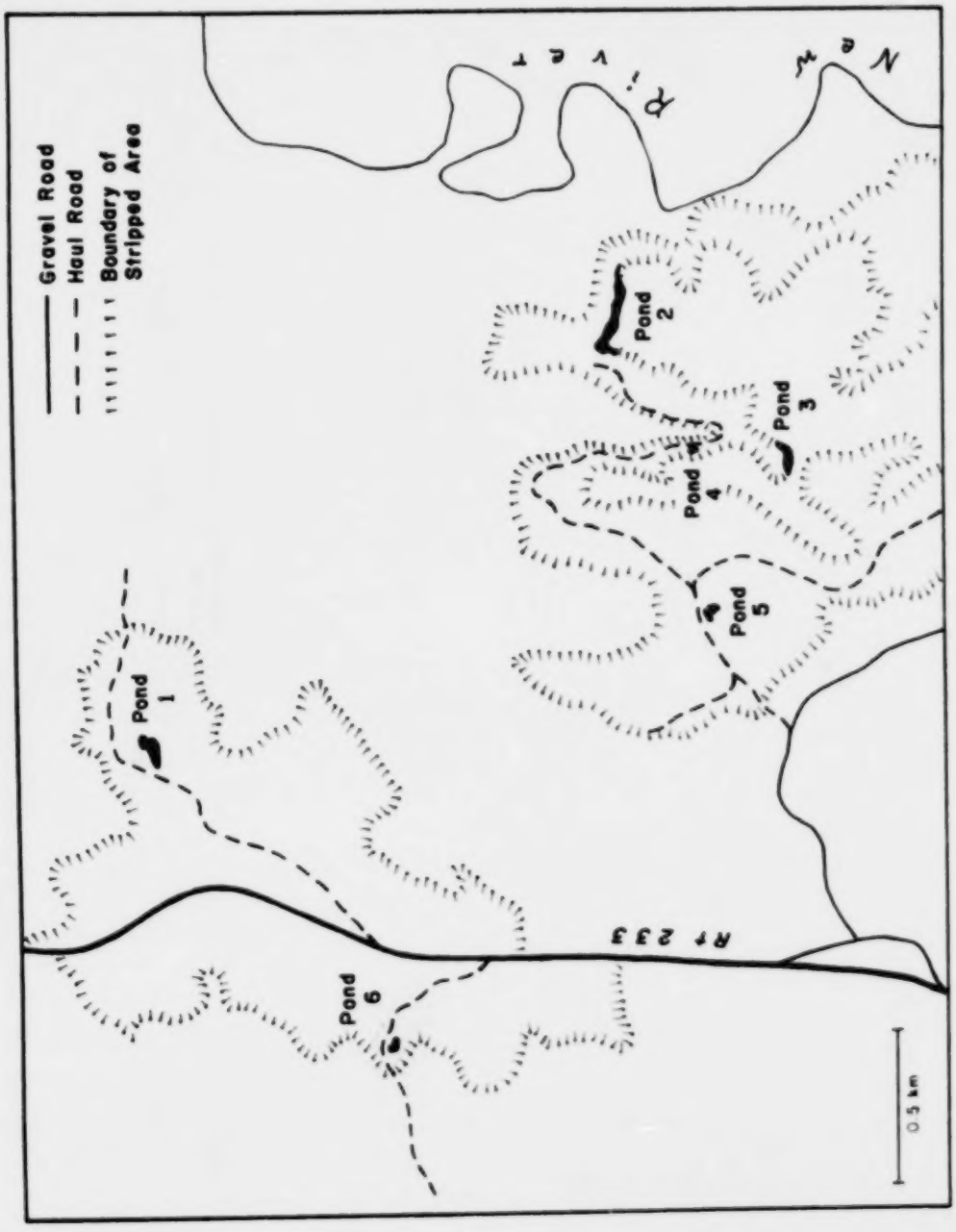

Figure 3. Map of Brilliant strip mine study area, showing locations of the six study ponds.

Radioisotope analysis and determination of heavy metal concentrations of bottom sediments in each of the strip mine ponds and Buttahatchee Lake were performed in June 1977 by TVA's Radiological Hygiene Branch and Laboratory Branch. Physicochemical analysis of pond and lake water began in January 1978 and continued at trimonthly intervals through October 1978. Water to be analyzed was collected from one permanent station near the shore of each pond and Buttahatchee Lake every other day for a period of two weeks during each trimonthly sampling period. The pH of the water was determined using an Orion specific ion meter (Model 401). Dissolved oxygen concentrations were measured using a Y.S.I. Model 54 oxygen meter. A Y.S.I. Model 335-C-T meter was used to measure conductivity. Water temperature was determined using a mercury bulb thermometer. All measurements were taken at a depth of about five centimeters. Other physicochemical analyses of water samples were performed by the Laboratory Branch within the Division of Environmental Planning, TVA.

Monthly sampling for chironomid larvae began in March 1978. In June, Marion County Lake was added as a second reference site because its smaller size, lentic nature, and species composition appeared to more closely resemble the habitat of the strip mine ponds. Also, D. pulcher was rarely collected in Buttahatchee Lake, whereas it was common in Marion County Lake. Twenty-three core samples (dia. 7.5 cm) were collected from one pond in each age class and from Buttahatchee Lake to a depth of five cm in the sediment. Each core sample was preserved in 95% ethanol until the larvae could be picked and mounted on microscope slides for identification and enumeration. Slide mounting essentially followed the CMC-10 procedure outlined by Beck,[17] except that polyvinyl lactophenol was used as the mounting medium.

Water quality analysis was conducted trimonthly so that each pond and reference lake could be characterized for each season. Parameters showing pond differences were plotted for simple comparisons. Cluster analysis was used to classify the ponds into groups with most similar characters. In this way, differences in the water quality of each pond could be compared with differences in the water quality of each control lake during each season. Water quality differences could then, in turn, be compared with chironomid species diversity, and the incidence of abnormalities in the Djalmabatista pulcher populations. Linear regression analysis, using the principles of least squares, was used to generate Pearson correlation coefficients between each parameter measured in order to determine the degree of association between parameters.

The chironomid larvae collected at monthly intervals were identified and enumerated to estimate relative population densities and species diversity.[18] Pielou's percentage of similarity[19] was used to compare the sites based on their chironomid taxa, the data being pooled for the 10 sampling dates. This measure of similarity takes into account relative abundances of species in addition to sharing. The D. pulcher larvae were examined to determine the degree of variation in ligula structure. A ligula with four symmetrical teeth was scored as normal, whereas one with a different number of teeth or obvious asymmetry was scored as abnormal. For test of significance, abnormalities in the strip mine ponds were pooled for the period June to October 1978 and compared with the number found in

Marion County Lake using binomial proportions based on probability distribution of chi-square.[20] The lengths of antennal segment 1, the ligula, and the paraglossae were also determined. These structures and the way they were measured are shown in Figure 4.

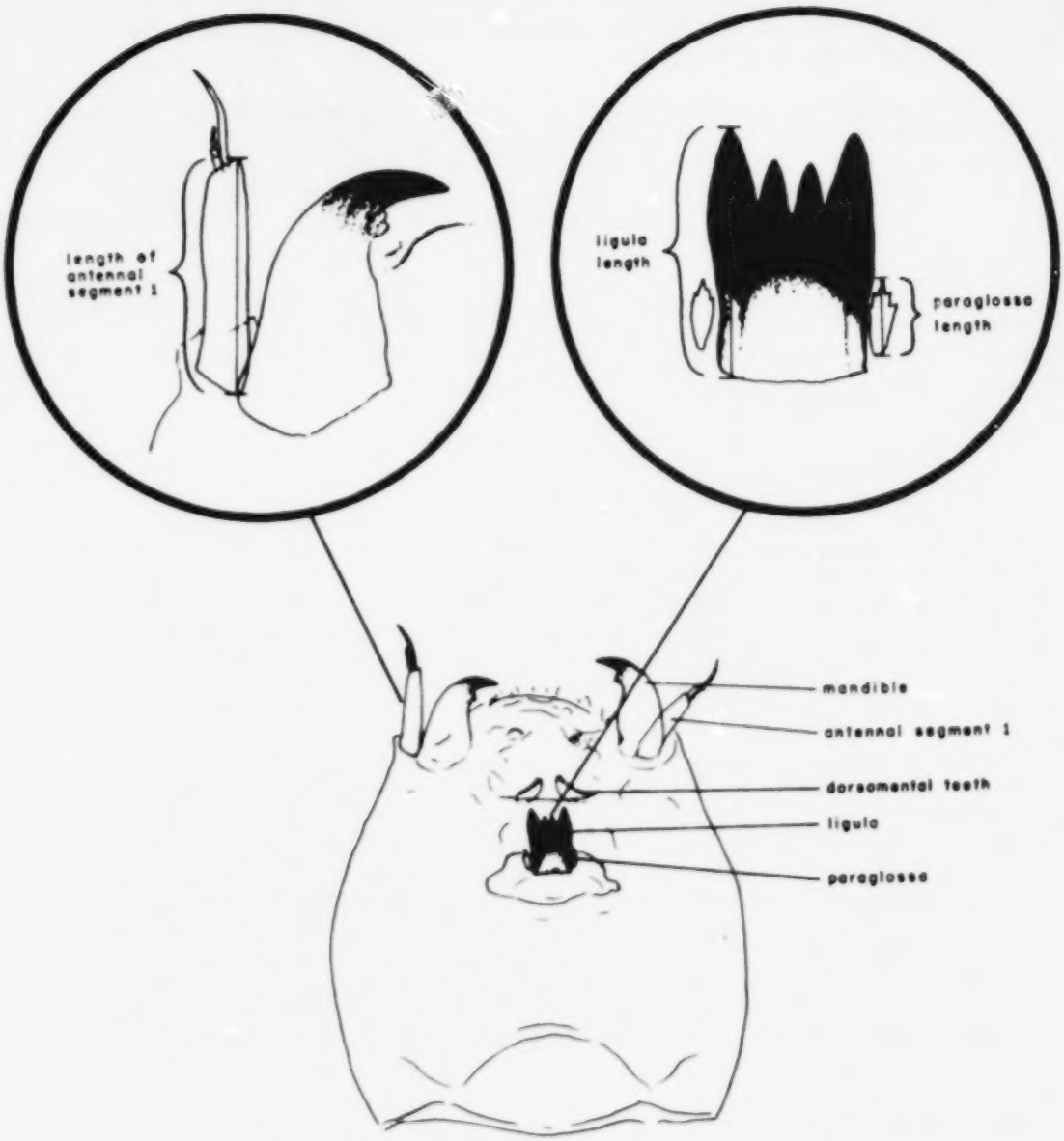

Figure 4. Head capsule of fourth instar larva of Djalmabatista pulcher, showing nomenclature of structures and method of measuring antennal segment 1, the ligula, and the paraglossa.

RESULTS AND DISCUSSION

Radioactivity and Heavy Metal Concentrations in Sediments

Gross alpha and beta radioactivity and heavy metal concentrations of the strip mine ponds and reference lake are presented in Tables 1 and 2, respectively. Alpha and beta radioactivity of the pond sediments were not significantly different than the lake values; some pond values were, in fact, lower than lake values.

Differences in heavy metal concentrations between pond and lake sediments were also not significant. However, copper, nickel, and zinc concentrations were slightly greater in ponds 2, 3, and 4 than in the reference lake. In addition, the concentrations of chromium, copper, iron, nickel, and zinc were greater in pond 5 than in the reference lake. Lead was less in all ponds compared with the reference lake.

These data indicate that radioactivity and heavy metal concentrations, would not contribute to population anomalies in the strip mine ponds since pond values are not significantly different and may be less than the reference lake values.

Water Quality Measurements

Since chironomids spend most of their lives in contact with surface waters, water quality is important in determining the health and success of individuals within the total population. The exposed rock and soil found in the strip mine area can have a profound impact on the rates of accumulation and availability of trace elements, cations, anions, and other dissolved and suspended solids in the strip mine ponds. Consequently, these ponds are unique habitats for aquatic organisms, where saline enrichment may be one of several factors influencing the life within them.

Results of the water quality analysis of the six strip mine ponds and Buttahatchee and Marion County Lakes are presented in Appendix A, Tables A-1 through A-4. Detailed description and figures of the more important water quality parameters are presented below. In general, greatest differences in the values of calcium and magnesium, sulfate, calcium/magnesium hardness, conductivity, and dissolved solids were observed between each pond and control for each sampling period. Variation in their values was also noted between ponds of the same age, indicating a lack of correlation between pond age and water quality. Temperature, dissolved oxygen, nitrogen (Kjeldahl), and phosphorus concentrations varied little between each pond and reference lake, although seasonal differences alone were observed.

1. pH and Alkalinity

Mean pH and alkalinity values are presented graphically in Figures 5 and 6, respectively. Highest values of pH and alkalinity were observed in the younger ponds 1 and 2. This is of particular interest

TABLE 1. GROSS ALPHA AND BETA RADIOACTIVITY OF SEDIMENTS COLLECTED AT SIX OF THE STUDY SITES IN JUNE 1977

		Activity	
Location	Sample	Gross α (pCi/g)	Gross β (pCi/g)
Buttahatchee Lake	1	16.16 ± 1.61	58.31 ± 1.38
	2	18.18 ± 1.73	62.74 ± 1.44
	3	14.22 ± 1.52	61.49 ± 1.41
Pond #1	1	5.58 ± 1.02	29.55 ± 1.00
	2	6.18 ± 1.06	62.02 ± 1.38
Pond #2	1	13.18 ± 1.47	60.59 ± 1.39
	2	11.54 ± 1.38	63.36 ± 1.42
Pond #3	1	15.26 ± 1.57	67.34 ± 1.47
	2	9.16 ± 1.25	48.88 ± 1.25
Pond #4	1	14.03 ± 1.46	62.07 ± 1.41
	2	15.11 ± 1.57	74.76 ± 1.54
Pond #5	1	16.31 ± 1.62	80.06 ± 1.59
	2	16.45 ± 1.63	79.20 ± 1.58

TABLE 2. HEAVY METAL CONCENTRATIONS IN THE SEDIMENTS OF THE STRIP MINE PONDS AND REFERENCE LAKE. MEAN VALUES WERE CALCULATED FROM FOUR LAKE SAMPLES AND TWO SAMPLES PER POND

Location	Statistic	Metal (µg/gm)							
		Cd	Cr	Cu	Fe*	Hg	Ni	Pb	Zn
Buttahatchee Lake	Mean	2	23	20	29	<.10	34	45	68
	range	1-2	18-27	19-21	26-32	-	30-38	40-52	56-77
Pond 1	Mean	2	16	20	25	<.10	31	18	62
	range	1-2	9-22	16-23	19-31	-	22-39	12-24	-
Pond 2	Mean	2	20	23	24	<.10	47	24	74
	range	-	19-21	21-24	23-25	-	46-48	21-26	66-82
Pond 3	Mean	2	20	24	27	<.10	39	28	72
	range	-	18-21	20-27	22-32	-	25-52	23-32	52-91
Pond 4	Mean	2	23	26	23	<.10	27	32	53
	range	-	22-24	25-26	-	-	25-29	30-33	51-55
Pond 5	Mean	2	29	25	35	<.10	45	31	75
	range	-	25-32	22-27	34-36	-	44-45	-	72-77

*mg/gm

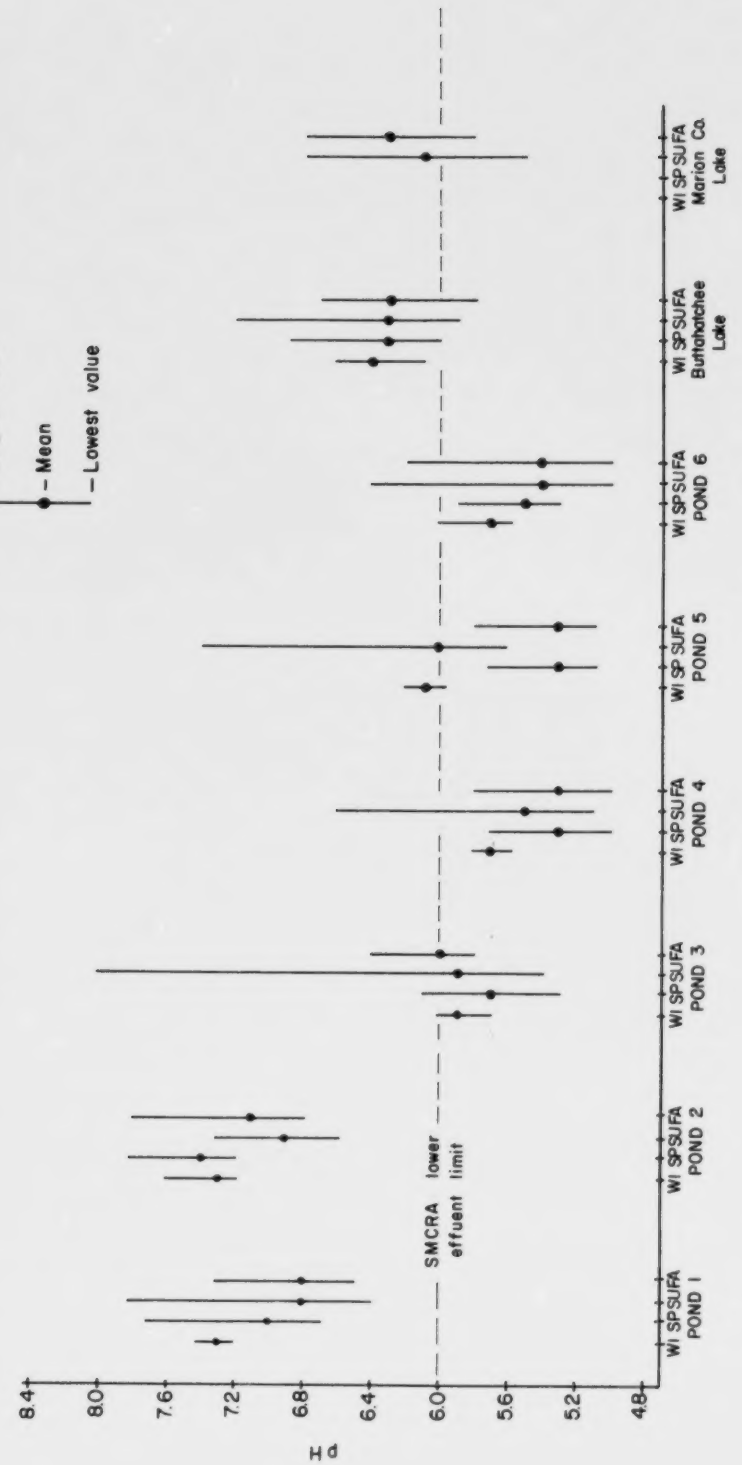

Figure 5. Mean pH values of the strip mine ponds and reference lakes for the 1978 sampling periods (calculated from hydrogen ion concentrations). (WI = winter, SP = spring, SU = summer, FA = fall)

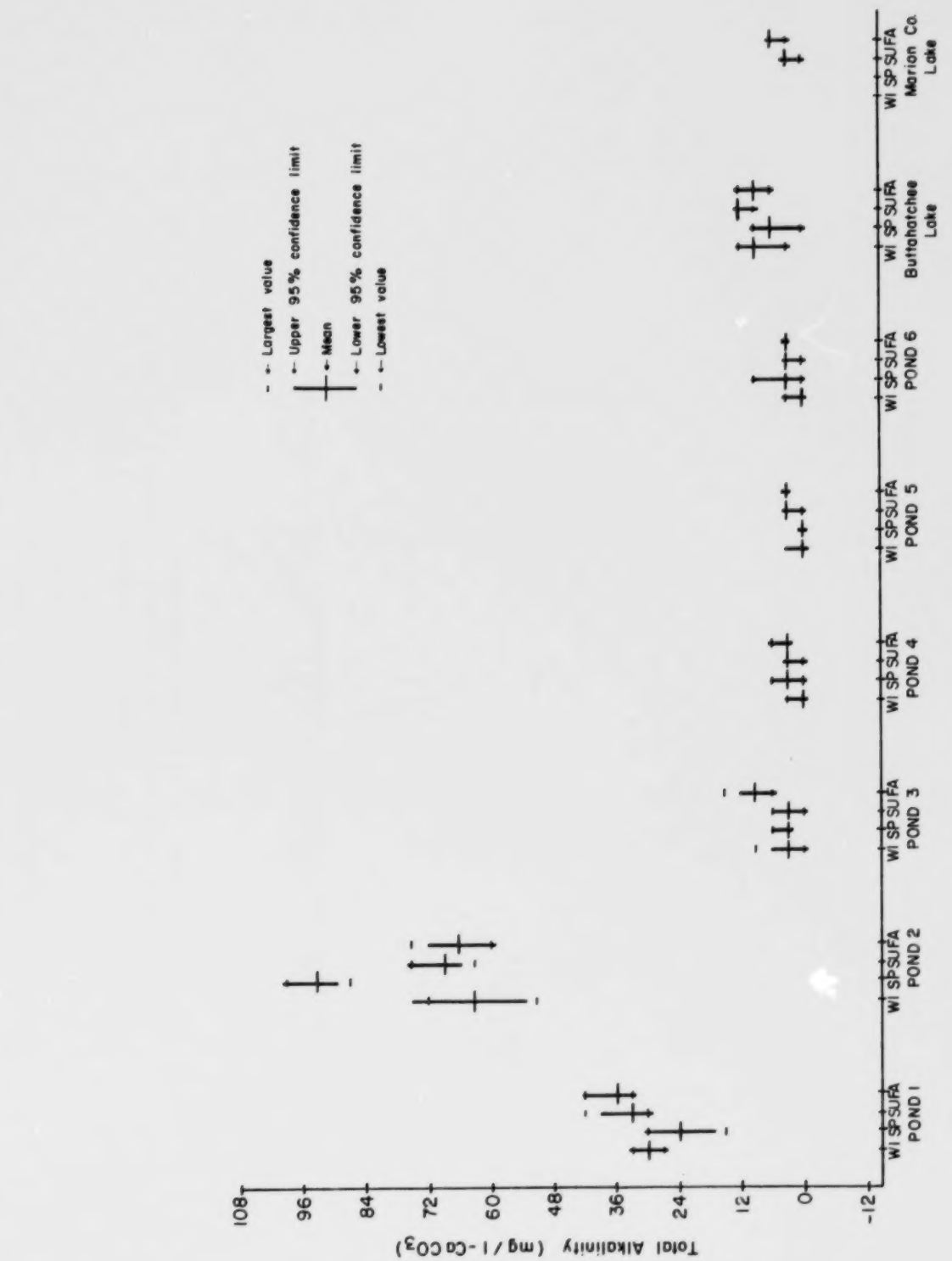

Figure 6. Total alkalinity of the strip mine ponds and reference lakes for the 1978 sampling periods.

since these values were higher than those observed in the reference lakes. Curtis[21] in Kentucky and Plass[22] in West Virginia have observed similar behavior in streams, where pH and alkalinity increased after mining disturbances. Minear [23] and Cox, et al.[24] also noted higher pH and alkalinity values in streams draining disturbed watersheds compared to virgin, forested watersheds.

In the older ponds 3, 4, 5, and 6, pH and alkalinity values were lower than those of ponds 1 and 2 and the reference lakes. Although there is no surface discharge from these ponds, mean values of pH were generally lower than the minimum effluent value (pH = 6.0) allowable under the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

These data suggest that mining increases pH and alkalinity in younger ponds as limestone and other carbonate rocks are exposed. As the ponds age, the weathering and accumulation of other noncarbonate minerals and rock gradually reduce the buffering capacity and, as a result, the pH and alkalinity. Lower pH and alkalinity values may also result from the seepage of ground water through deposits of iron pyrites, which are known to cause acid mine drainage and are found in varying quantities throughout the strip mine area.

2. Ca-Mg Hardness

Just as the pH and alkalinity reflect the presence of carbonates in the overburden, so does calcium-magnesium (Ca-Mg) hardness. Precipitation and runoff contact newly exposed materials, resulting in the dissolution of soluble species such as calcium and magnesium cations. The presence and quantities of these cations determine the degree of Ca-Mg hardness of the ponds.

Ca-Mg hardness values of the strip mine ponds and reference lakes are presented in Figure 7. Generally, Ca-Mg hardness was higher in the ponds with values ranging from 35.5 mg/l in pond 6 to 390.0 mg/l in pond 2. Pond 2 may be spring-fed, possibly explaining its high value. Hardness values ranged from 6.2 mg/l in Marion County Lake to 21.2 mg/l in Buttahatchee Lake. Lower values in both reference lakes suggest that the rate of weathering of rock and erosion of soil is decreased due to the forested areas and littoral vegetation surrounding each lake.

3. Iron and Manganese

Iron and manganese are closely related transition elements and are among the major components of the earth's crust. These elements are important reactants in redox processes in natural waters and are also essential micronutrients of freshwater flora and fauna.[25] Concentrations of iron in strip mine discharges and ponds can be much greater than in natural waters, partly because of chemical and physical release of the ferrous (Fe^{++}) or the ferric (F^{+++}) state. Oxidation of ferric sulfide (pyrite), a mineral common to coal-bearing strata, can lead to elevated hydrogen ion [H^{+}] concentrations (lowered pH) in poorly buffered systems.

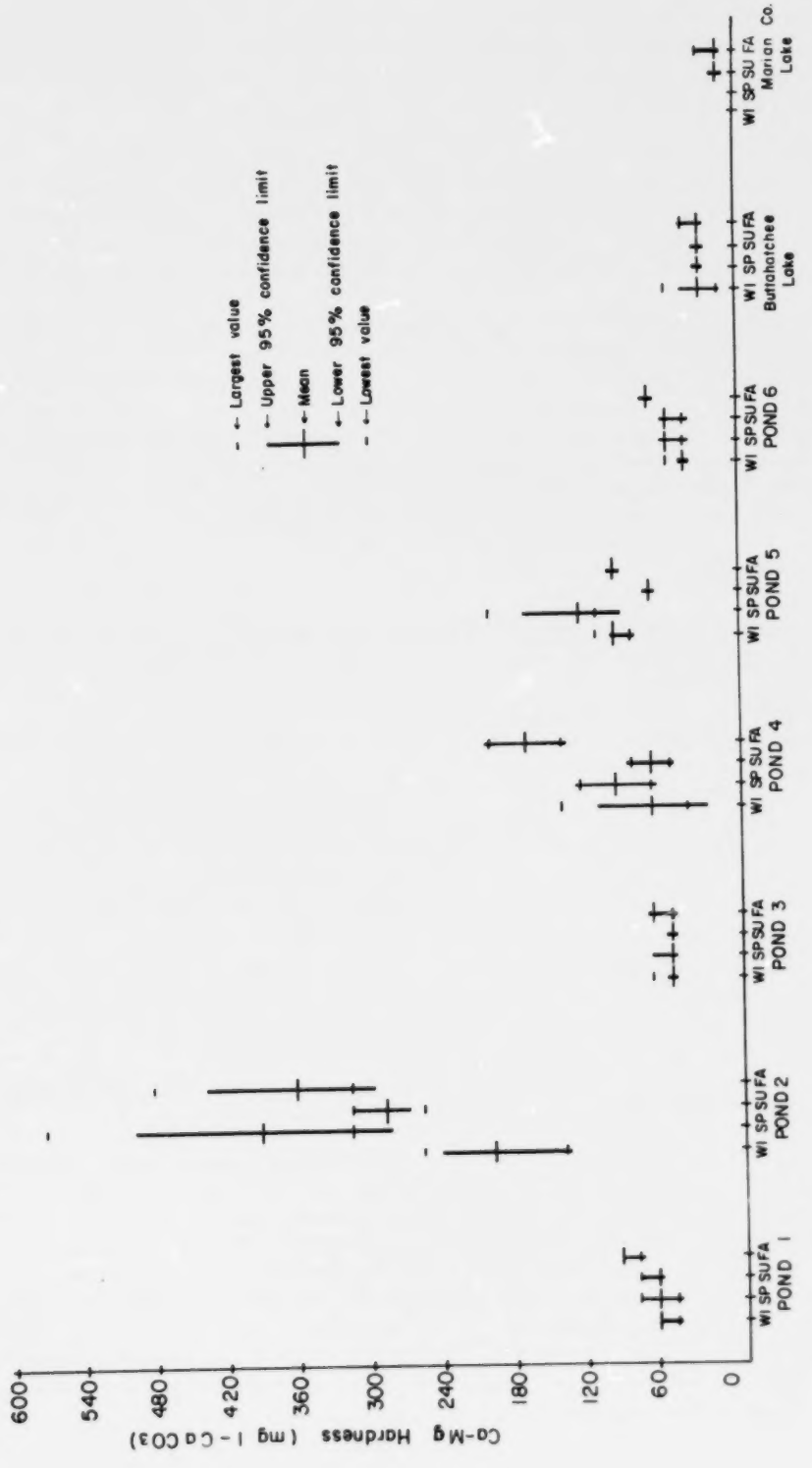

Figure 7. Ca-Mg hardness of the strip mine ponds and reference lakes for the 1978 sampling periods.

Total iron and manganese concentrations in the strip mine ponds are presented in Figures 8 and 9. Values for both elements were well below the maximum allowable values established under the SMCRA (7.0 and 4.0 mg/l, respectively) in the strip mine ponds and the reference lakes (0-3.4 mg/l). Total iron concentrations in the strip mine ponds were not significantly different from values in the reference lakes. Manganese concentrations were low in the reference lakes and ponds 1 and 2 (0-0.86 mg/l), but higher and more variable in ponds 3, 4, 5, and 6 (0.07-2.3 mg/l). High quantities of manganese in these ponds were probably due to its increased solubility at lower pH values.

4. Sulfate

The oxidation of ferric sulfides in coal mine areas can also result in the production of sulfate.[26] Acidity may also increase, depending on the amount and availability of strata with sufficient neutralizing potential.

Sulfate concentrations were higher in the strip mine ponds (6.0-350.0 mg/l) than in the reference lakes (1.0-22.0 mg/l) with highest values in pond 2 throughout the study period (Figure 10). Sulfate was closely related to dissolved solids ($r = 0.98$), hardness ($r = 0.93$), and conductivity ($r = 0.88$), a condition which reflects its close association with calcium, magnesium, and other dissolved minerals. Higher sulfate concentrations, however, were not accompanied by increased acidity.

5. Dissolved and Suspended Solids

In conjunction with the specific water quality parameters measured, concentrations of dissolved and suspended solids were determined (Figures 11 and 12). Although these parameters are not precise measurements of specific chemical interactions, they are important indicators of the rates of erosion and silting associated with strip mining.

Dissolved solids were higher and more variable in the strip mine ponds than in the reference lakes. Highest values were observed in pond 2 (220-520 mg/l), while lowest strip mine pond values were observed in pond 3 (70-120 mg/l). There was a high degree of linear correlation between concentrations of dissolved solids and sulfate ($r = 0.98$), Ca-Mg hardness ($r = 0.96$), magnesium ($r = 0.94$), calcium ($r = 0.92$), and conductivity ($r = 0.87$).

All values of suspended solids were below the maximum allowable value established under the SMCRA (70 mg/l) with the exception of a slightly higher value obtained in pond 1 during the summer sampling period (110 mg/l). This is in contrast to suspended sediment concentrations in affected streams and rivers, where values are commonly 5 to 10 times higher. The lower values of suspended sediments in the strip mine ponds were probably a result of the rapid settling out of suspended material from the water column, a physical characteristic of nonflowing waters.

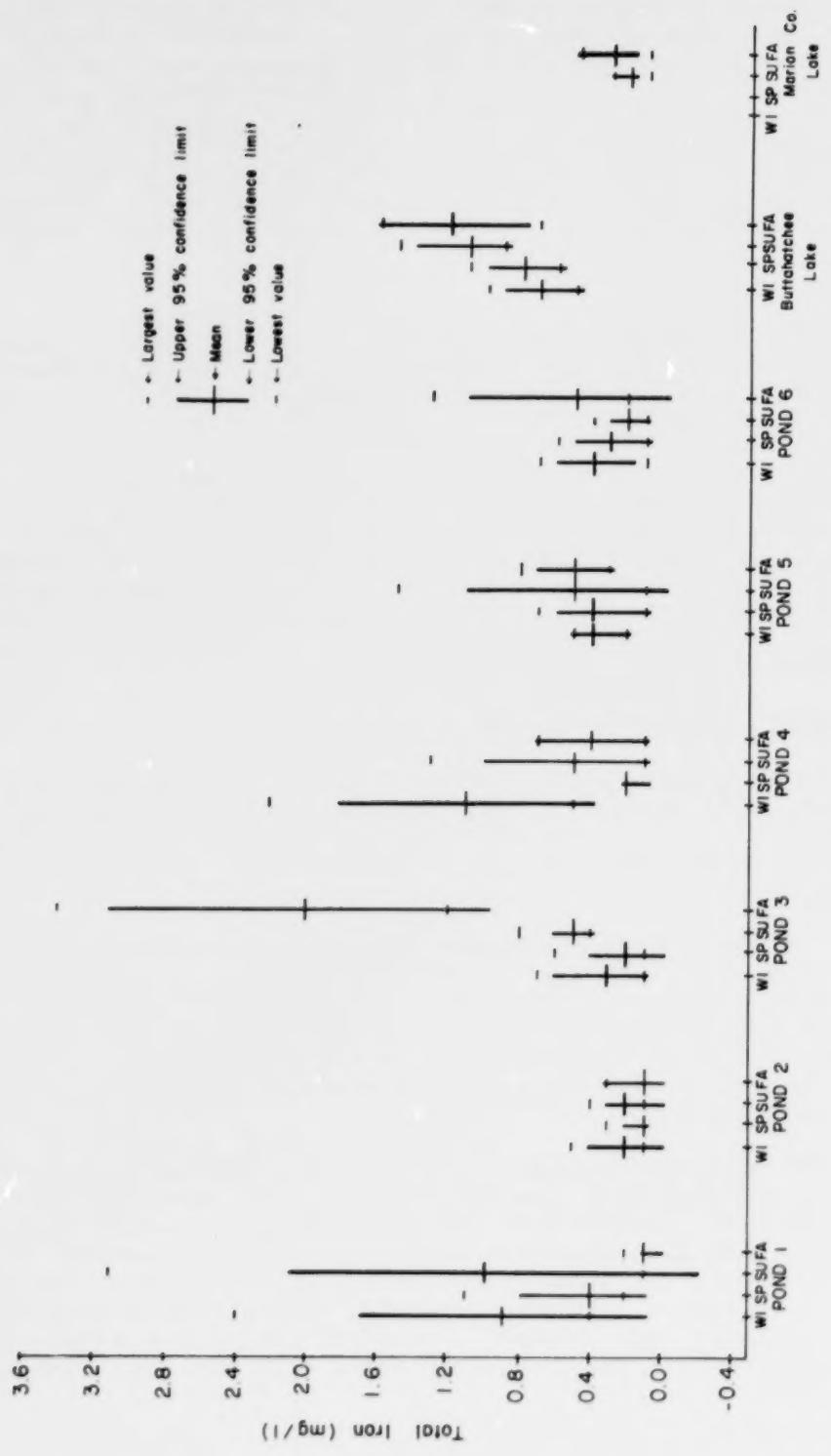

Figure 8. Total iron concentrations of the strip mine ponds and reference lakes for the 1978 sampling periods.

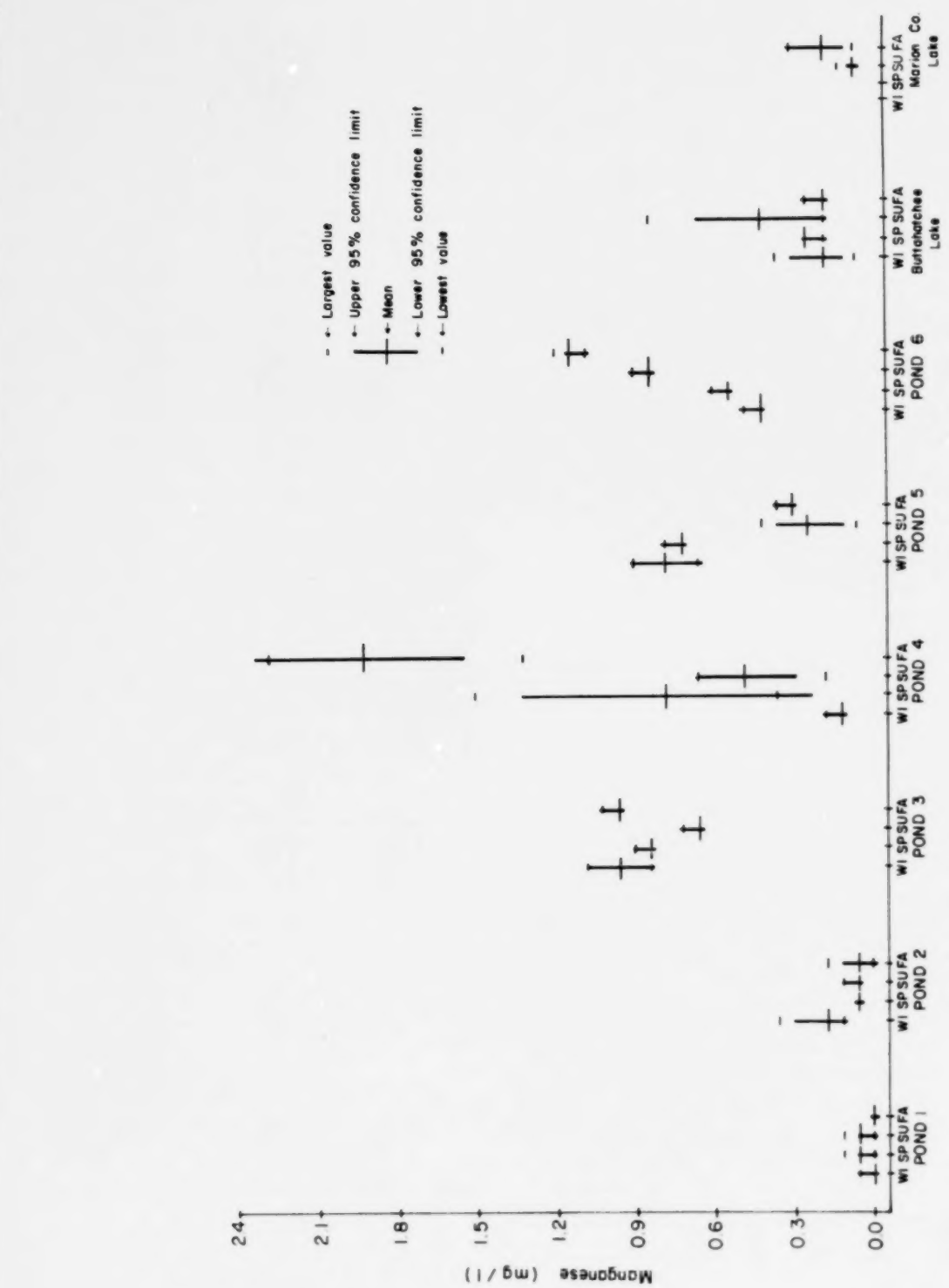

Figure 9. Manganese concentrations of the strip mine ponds and reference lakes for the 1978 sampling periods.

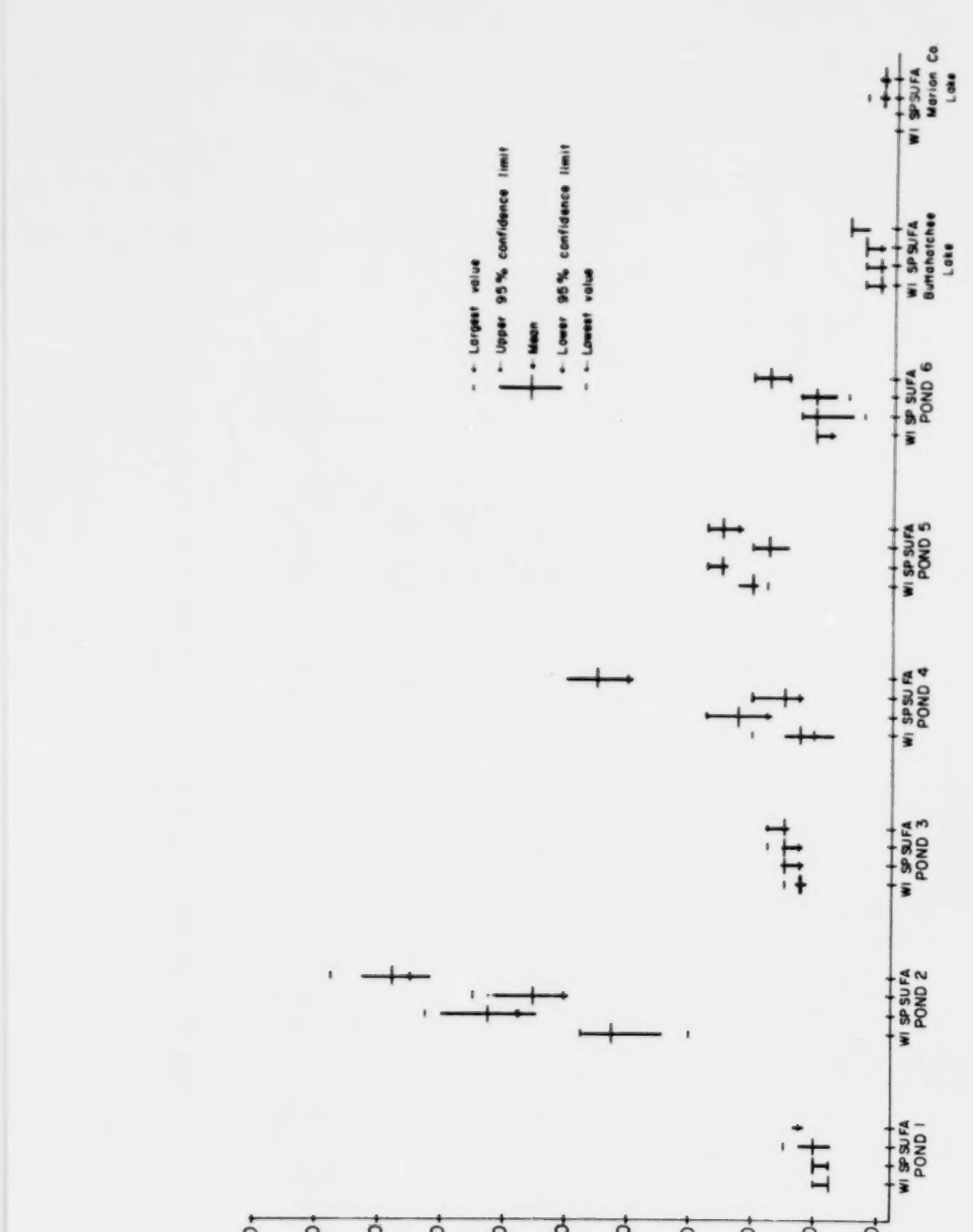

Figure 10. Sulfate (SO_4) concentrations of the strip mine ponds and reference lakes for the 1978 sampling periods.

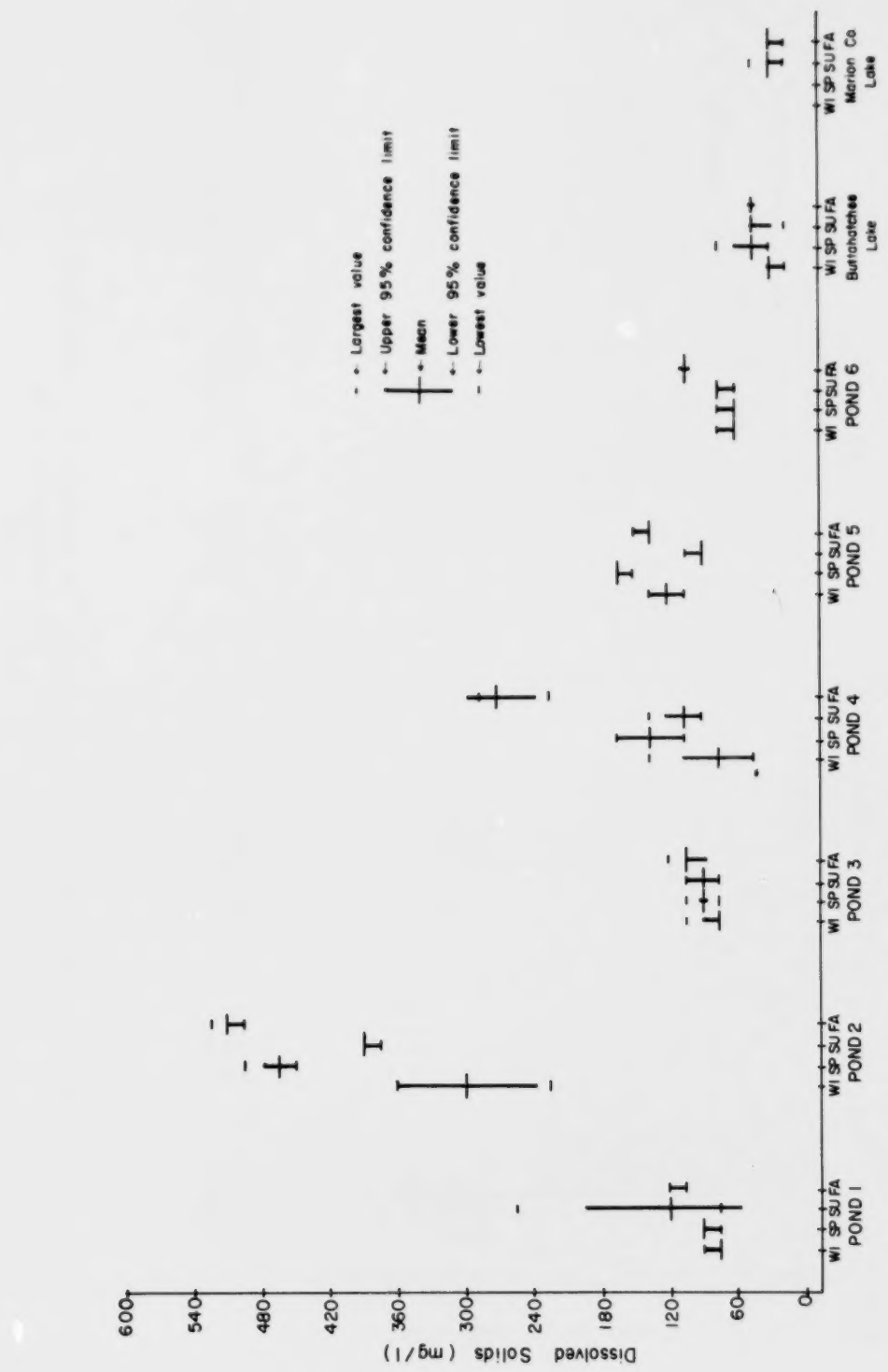

Figure 11. Dissolved solids concentrations of the strip mine ponds and reference lakes for the 1978 sampling periods.

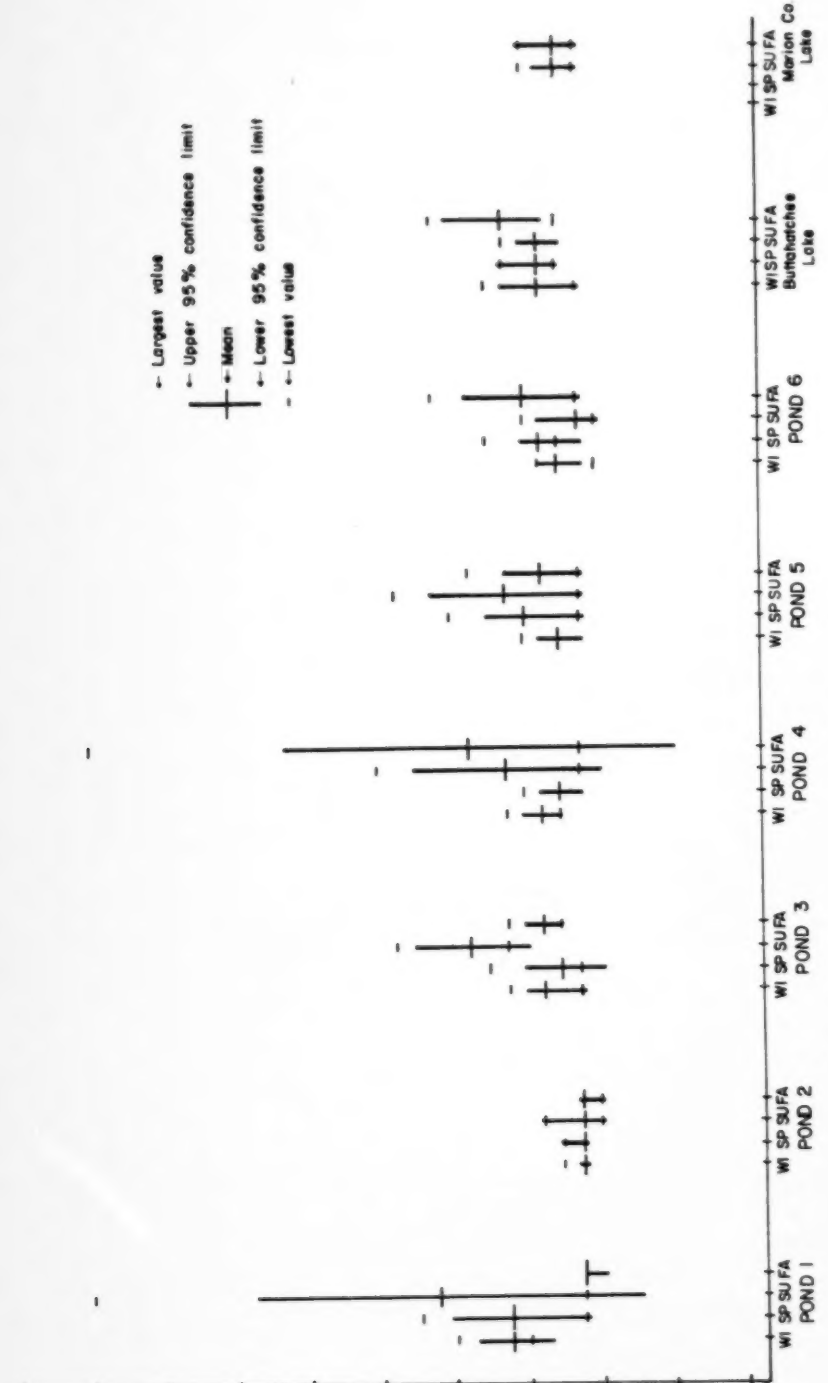

Figure 12. Suspended solids concentrations of the strip mine ponds and reference lakes for the 1978 sampling periods.

6. Relationship of Water Quality to Rainfall

The rates at which rocks are weathered and soil eroded surrounding the strip mine ponds are largely a function of rainfall. The resulting surface runoff and subterranean seepage during periods of moderate and heavy rainfall can leach potentially toxic substances, such as heavy metals and salts, and wash dissolved and suspended solids into the ponds.

Cumulative weekly rainfall amounts for 1978 were calculated from daily amounts collected in a gage located in Hamilton, approximately 30 km east of Buttahatchee Lake and the strip mine study area and 12 km north of Marion County Lake (Figure 13). Despite its location outside the immediate study area, the gage was useful in assessing the general climatological conditions of the county and any resulting physical or chemical changes of the reference lakes or strip mine ponds.

Although none of the survey periods were entirely free from rainfall, the cumulative weekly rainfall amounts were generally less than 1.0 cm. A significant amount of rain fell during the four weeks prior to the winter survey period and the week prior to the summer survey period, raising pond water levels and increasing suspended sediment loads and possibly diluting dissolved water quality constituents. However, no significant ($P < 0.0001$) linear correlations were observed between the water quality variables measured and cumulative antecedent rainfall amounts except for temperature ($r = -0.42$) and total organic carbon ($r = 0.37$). Additional significant correlations may have existed if rainfall gaging had been in the immediate study area.

7. Cluster Analysis

A phenogram grouping similar strip mine ponds and reference lakes by water quality is presented in Figure 14. The water quality parameters and their mean values used in the cluster analysis are presented in Table 3. The results of the analysis clustered the ponds and the reference lakes into two distinct groups. Furthermore, the ponds were divided into two additional groups with ponds 1 and 2 in one group and ponds 3, 4, 5, and 6 in the other. This grouping supports the observed higher alkalinity and pH of ponds 1 and 2 in relation to the other ponds. In addition, ponds 3 and 6 were grouped together as were ponds 4 and 5, although in each case the ponds were approximately six years apart in age.

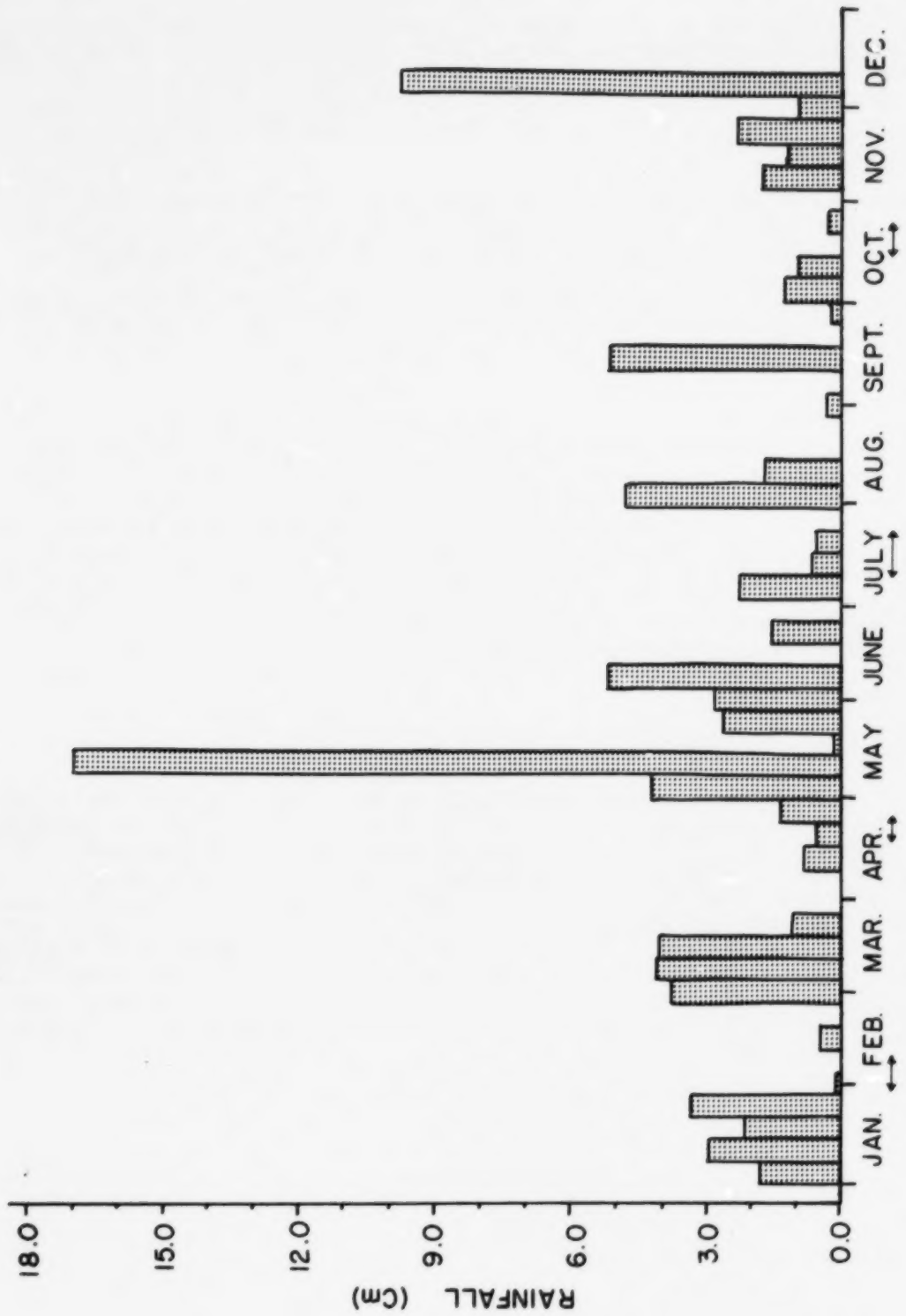

Figure 13. Cumulative weekly rainfall amounts (cm) in Hamilton, Marion County, 1978.

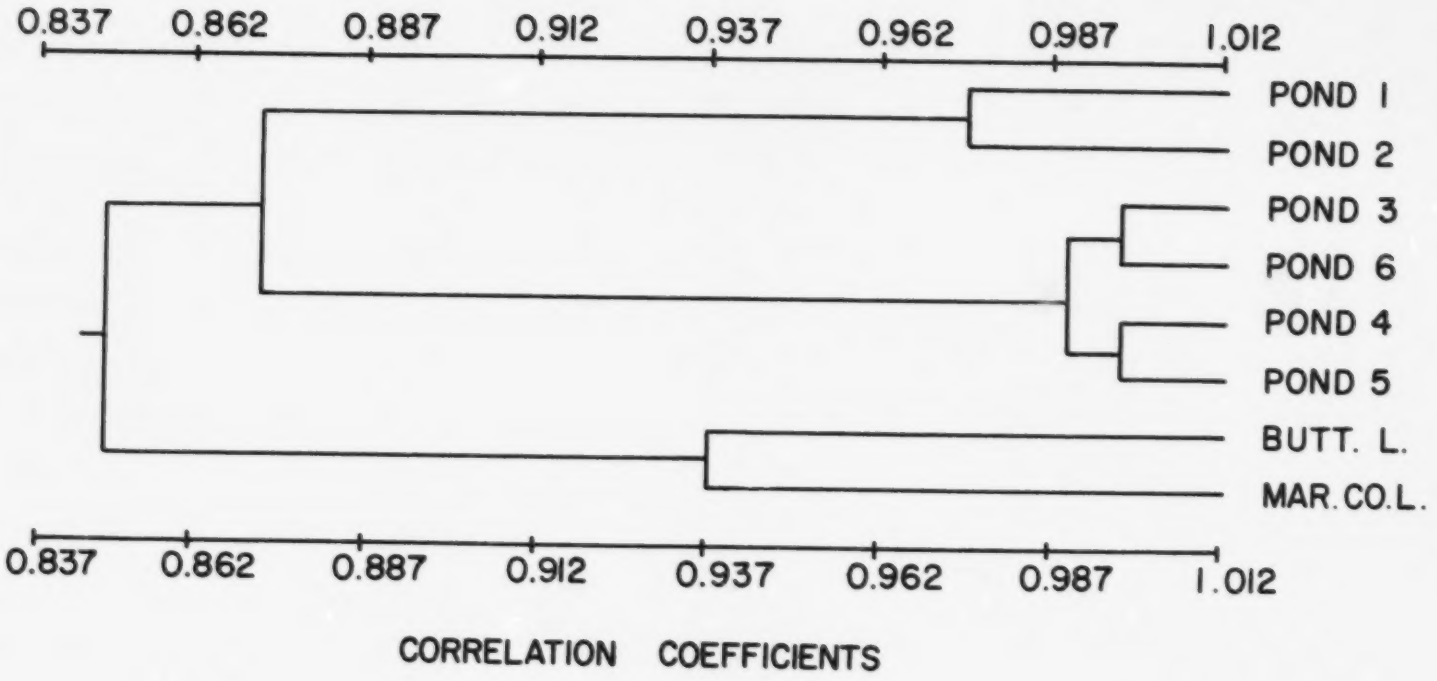

Figure 14. Clustering of the strip mine ponds and reference lakes based on selected water quality parameters.

TABLE 3. SELECTED WATER QUALITY PARAMETERS AND THEIR MEAN VALUES USED IN THE CLUSTER ANALYSIS

Parameter*	Station							
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Butt. Lake	M.C.L.
pH (S.U.)	6.9	7.1	5.9	5.4	5.6	5.5	6.3	6.2
Alkalinity	87.7	282.7	12.0	8.5	4.0	9.2	17.4	3.0
Acidity	12.9	13.1	8.5	9.4	10.4	10.6	10.0	2.9
Ca-Mg Hardness	68.0	307.9	49.3	91.7	88.5	43.0	16.0	6.8
Total Iron	0.60	0.15	0.77	0.58	0.45	0.36	0.96	0.27
Manganese	0.03	0.10	0.88	0.83	0.52	0.74	0.26	0.13
Sulfate	40.9	238.8	56.1	95.4	87.9	45.6	7.9	2.8
Conductivity (μmhos/cm)	135.0	513.6	136.0	189.6	194.5	122.0	45.8	22.3
Dissolved Solids	101.7	413.8	90.8	145.8	130.0	75.8	36.3	23.3
Suspended Solids	18.6	4.3	15.3	16.9	13.6	10.0	14.9	9.4

*Units are mg/l unless otherwise indicated.

Chironomidae Species Composition and Diversity

The total number of larvae of each of the 35 taxa collected at each site during this study is given in Table 4. The most commonly collected species were Clinotanypus pinguis, Djalmabatista pulcher, Procladius spp., an unidentified genus of Orthocladiinae, Polypedilum sp., Cladotanytarsus sp., Micropsectra sp., and Tanytarsus spp. Six taxa were taken only at Buttahatchee Lake, whereas two taxa were taken only at Pond 4, two only at Marion County Lake, and one only at Pond 1.

The largest number of chironomid taxa, 28, was found at the Buttahatchee Lake site, whereas the strip mine pond and Marion County Lake sites yielded lower numbers of taxa (17 to 19). Diversity index values for the strip mine ponds and Marion County Lake were relatively low (1.269 to 1.784) compared to the value for Buttahatchee Lake (2.160). Greater diversity in types of substrate and aquatic plants at the Buttahatchee Lake site probably account for the greater chironomid diversity. However, Rosenberg[27] showed that chironomid diversity was not a good indicator of total diversity.

For a further comparison of the study sites based on their chironomid faunas, we used Pielou's[19] percentage of similarity (PS), setting the limit of similarity as a PS value above 50%. This procedure resulted in fairly good similarity between strip mine ponds 4 and 5, and between Marion County Lake and pond 4, and between Marion County Lake and pond 5 (Table 5). Pond 1 and Buttahatchee Lake were not similar to any of the other sites. These results match the results of the cluster analysis of the study sites based on the ten selected water quality parameters in that ponds 4 and 5 were grouped together (see Figure 14), but the similarity between Marion County Lake and ponds 4 and 5 based on chironomid faunas was not reflected in the cluster analysis. Composition of substrates may account for these different results.

The larval populations of Djalmabatista pulcher varied between ponds and sampling dates. Samples from pond 1 contained very few larvae compared to ponds 4 and 5 (Figure 15), whereas the population in Marion County Lake appeared to be more dense than in ponds 4 and 5. Populations increased in the spring, then slowly declined through the summer months to the lowest levels in August and September. However, the 1-month sampling interval was too great to allow precise monitoring of population fluctuations. D. pulcher was rare in Buttahatchee Lake (only 2 larvae in entire sampling period), probably because of the lack of unvegetated sand in shallow water, which D. pulcher appears to require.

Larvae of D. pulcher were readily assigned to instars by measuring the lengths of antennal segment 1 and the ligula. No overlap occurred between instar clouds II, III, and IV (Figure 16). No instar I larvae were found in the samples, probably because of their extremely small size. To obtain measurements of instar I larvae, eggs from fertile females were allowed to hatch in the laboratory. Length of antennal segment 1 varied from 0.012 to 0.015 mm and ligula length varied from 0.021 to 0.023 mm (n = 10). These measurements do not overlap with those for instar II. The ability to identify larval instars allowed us to determine whether ligula abnormalities occur throughout the larval stage.

TABLE 4. TOTAL NUMBER OF INDIVIDUALS OF EACH CHIRONOMID TAXON COLLECTED IN 207 CORE SAMPLES AT EACH SITE FROM MARCH 1 TO OCTOBER 17, 1978. (MARION COUNTY LAKE SAMPLED ONLY FROM JUNE 15 TO OCTOBER 17, TOTAL OF 115 CORE SAMPLES.) ASTERISK DENOTES SPECIES TAKEN AT ONLY ONE SITE.

TAXON	POND OR LAKE				
	1	4	5	B.L.	M.C.L
TANYPODINAE					
Ablabesmyia aspera	2	7	9	11	
Ablabesmyia parajanta	1	15	15	11	28
Clinotanypus pinguis		73		177	35
Djalmabatista pulcher	21	638	355	2	547
Labrundinia virescens*		2			
Larsia ?	1	94	4	7	4
Natarsia sp.*				2	
Procladius spp.	7	11	18	240	24
Tanypus spp.*				12	
ORTHOCLADIINAE					
Limnophyes ?*				1	
Psectrocladius sp. 1	3			1	1
Psectrocladius sp. 2	1	2	1		
Orthocladiinae genus unid.	85	53	10	4	6
CHIRONOMINAE					
Chironomus sp.				1	7
Cryptochironomus fulvus	1		5	33	25
Cryptocladopelma sp.*				4	
Cryptotendipes sp.	1	1	1	20	
Dicrotendipes sp.	2	3	8	16	
Einfeldia sp.*					1
Endochironomus nigricans			10	7	2
Glyptotendipes lobiferus*					11
Microtendipes sp.*		1			
Nilothauma sp.	4	2	1		
Pagastiella sp.		54	3	2	
Paracladopelma sp.*				4	
Paralauterborniella nigrohalteralis	1			359	
Paratendipes subaequalis		7		13	
Polypedilum sp.	170	24	30	27	77
Pseudochironomus sp.				5	94
Stictochironomus sp.	1			2	
Tribelos sp.*				1	
Cladotanytarsus sp.	1	37	2	133	166
Micropsectra sp.	5	5	29	100	32
Rheotanytarsus ?*	20				
Tanytarsus spp.		17	7	52	78
Total: 35 Taxa Totals:	327	1046	508	1247	1138
No. Species:	19	19	17	28	17
Diversity (H)	1.408	1.512	1.269	2.160	1.784
H_{max}	2.771	2.896	2.753	3.272	2.792
H_{min}	0.300	0.120	0.196	0.155	0.100
E	0.448	0.501	0.420	0.643	0.626

TABLE 5. SIMILARITY OF STUDY SITES BASED ON CHIRONOMID FAUNAS MEASURED BY PIELOU'S PERCENTAGE OF SIMILARITY (PS)

Study Sites[1]	No. of Taxa Shared	No. Taxa at First Site + No. Taxa at Second Site	PS
BL:MCL	15	45	30
BL:1	15	46	7
BL:4	15	47	18
BL:5	15	45	16
MCL:1	10	35	17
MCL:4	10	36	64
MCL:5	11	34	58
1:4	13	37	18
1:5	14	35	20
4:5	15	36	58

[1]BL = Buttahatchee Lake, MCL = Marion County Lake, and numbers refer to the strip mine ponds.

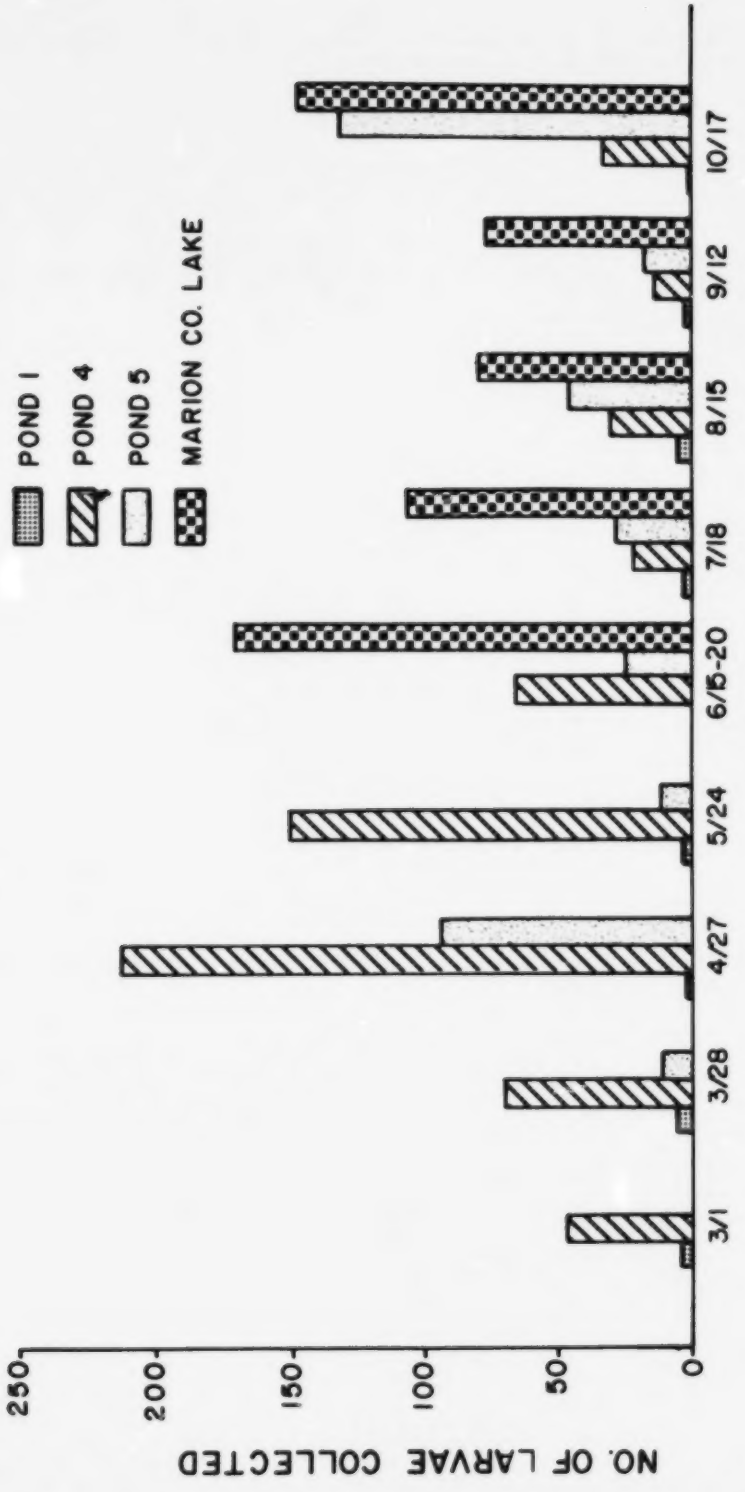

Figure 15. Number of larvae of Djalmabatista pulcher collected in 23 core samples on each sampling date at ponds 1, 4, and 5 and Marion County Lake.

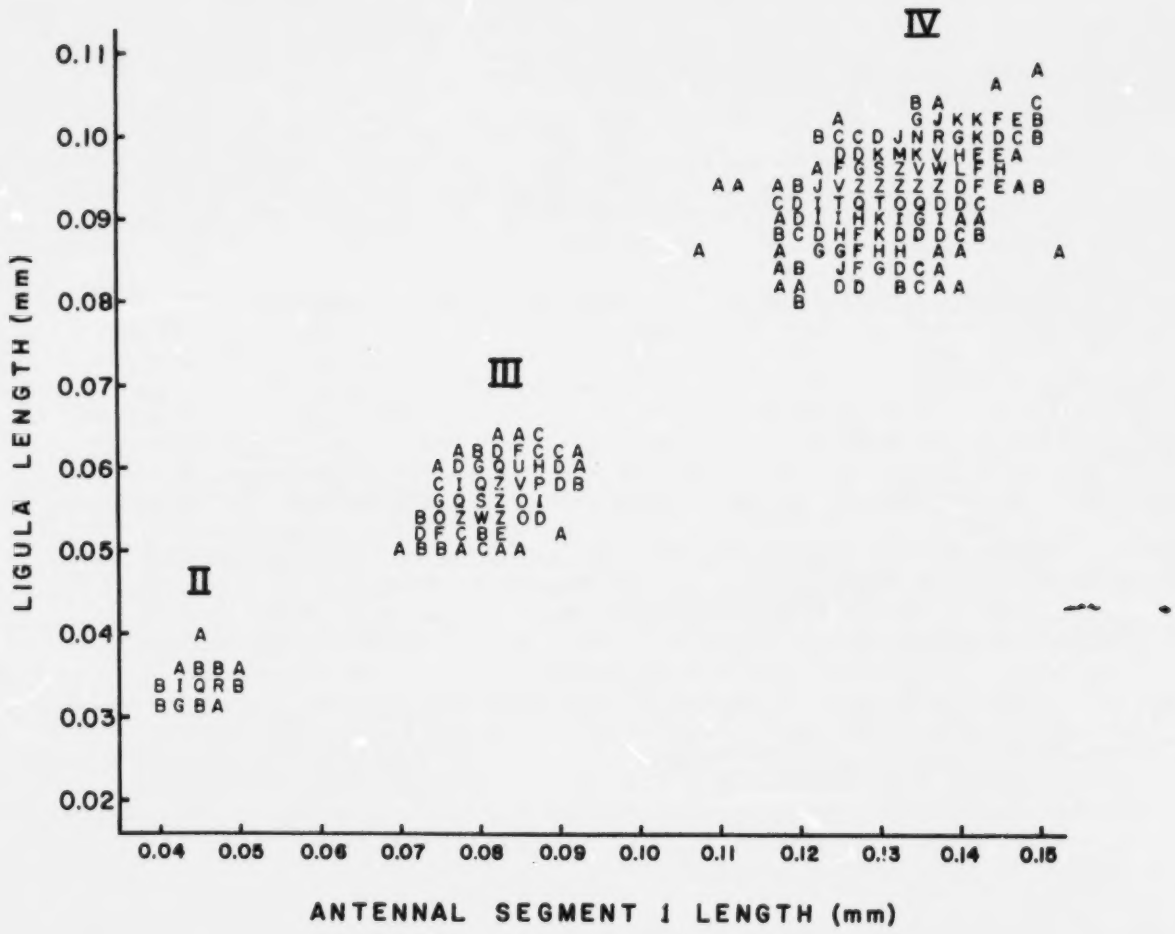

Figure 16. Instar clouds of Djalmabatista pulcher determined by length of antennal segment 1 and ligula length for all larvae collected. A = 1 observation, B = 2 observations, etc.; Z = 26 or more observations. Total N = 1,481

A comparison of the strip mine pond populations and the Marion County Lake population, using the length of antennal segment 1 and the ligula, showed that these structures are slightly larger on the average in the Marion County Lake population (Figure 17). These size relationships are fairly constant through all instars measured. Reasons for the size differences are unknown, but food availability and environmental stress are probable factors. Water quality analyses indicate that the strip mine ponds constitute a harsher environment, based on the higher values for dissolved solids, alkalinity, SO_4, Ca-Mg hardness, and manganese, and generally lower pH values than in the control lakes. However, these conditions may be suitable to certain species.

Ligula Abnormalities in Djalmabatista pulcher

The variations found in the shape of the ligula of Djalmabatista pulcher larvae are shown in Figures 18-20. The "normal" condition of four symmetrical teeth (Figures 18a and b) showed some very slight variations in the relative lengths and widths of the teeth, and occurred in over 90% of the larvae from each monthly collection.

Abnormally shaped ligulas included asymmetry of four teeth (Figure 18c), three teeth (Figure 18d), three teeth with 1 bifid (Figures 18f and 19a and b), curved teeth (Figures 19c-f), five teeth (Figures 20a-c), and asymmetry of five teeth (Figures 20d and e). One variant with six teeth (Figure 20f) that was found in the initial survey (September 28, 1976) was not seen in the monthly core samples of 1978. All of the other abnormal types were recurring. This wide range of variation in the shape of the ligula of one species has never been previously reported in the Tanypodinae.

Combining the ligula abnormalities found in all three strip mine ponds over the entire 1978 sampling period yielded an incidence of 4.0%. This percentage of abnormalities is higher than any incidence found in field samples of Chironomidae. Hamilton and Saether[11] reported that deformed larvae in five genera comprised approximately 1% of the chironomids collected in an extensive survey of Lake Okanagan and Lake Skaha in British Columbia. The deformities included malformed mouthparts and thickening of the body wall. Most of the deformed larvae were taken near known sources of agricultural or industrial pollution. Results of their preliminary laboratory attempts to induce deformities indicated that DDE (dichlorodiphenyldichloroethane, a metabolite of DDT) may be a causative agent and that it was to be investigated further.

We classed the ligula abnormalities in our D. pulcher larvae according to the number of teeth and their shape (Table 6). The most common type was five symmetrical teeth, followed by four asymmetrical teeth and three symmetrical teeth. Abnormal ligulas were found in all larval instars examined (II-IV) as shown in Figure 22 (1 of 69 instar II, 10 of 438 instar III, and 39 of 980 instar IV). Although the percentage of abnormal larvae appeared to increase as instar number increased, a chi-square test based on a 2 x 3 contingency table showed that the association was not significant ($P = .94$). The apparent increase in percentage was biased because of unequal sample sizes.

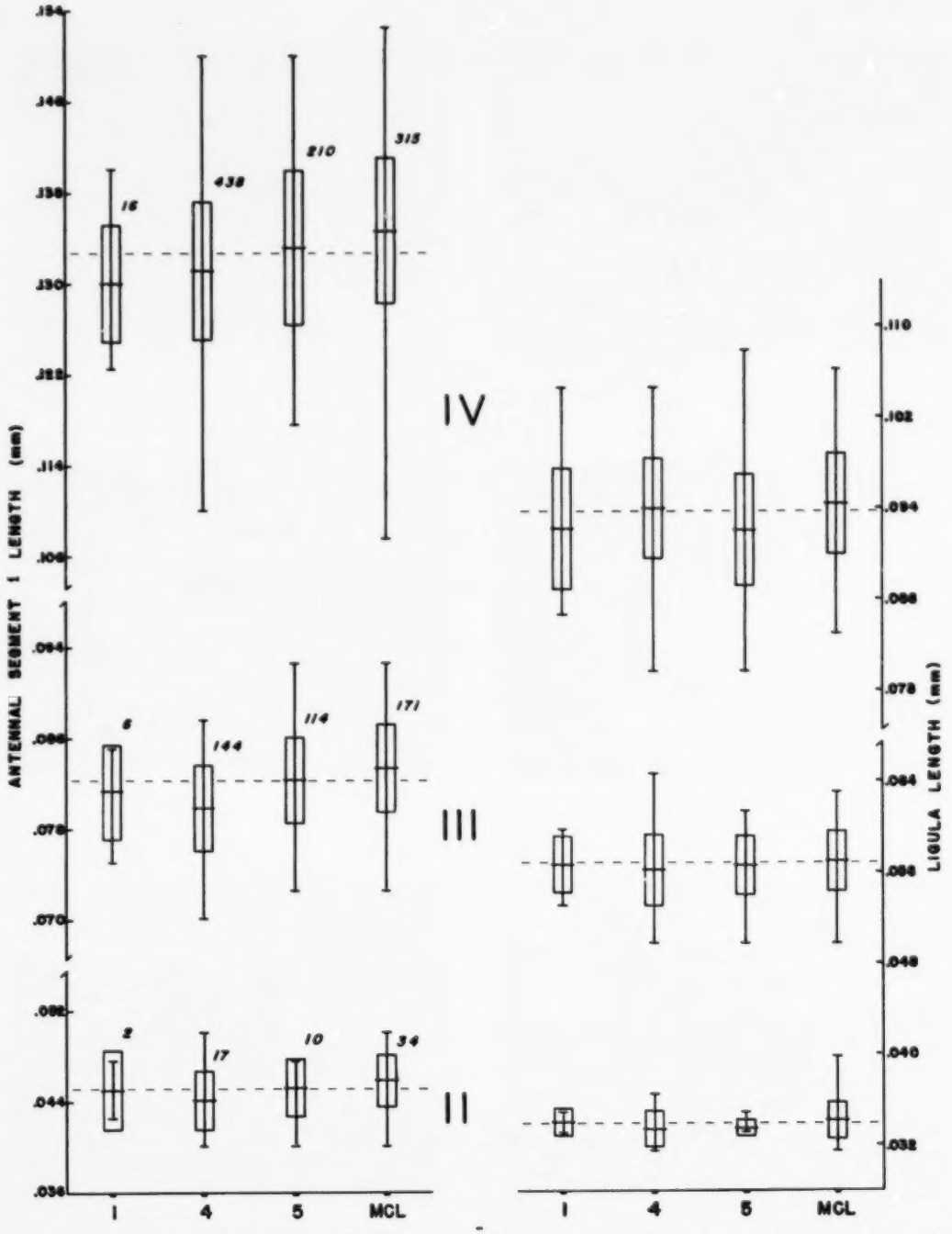

Figure 17. Comparisons of length of antennal segment 1 and ligula length in four populations of Djalmabatista pulcher (instars II-IV) in Marion County; data were pooled over 10 sampling dates from March to October 1978. Horizontal line = mean, rectangle = 2 x standard deviation, vertical line = range. Numbers in italics are the number of observations.

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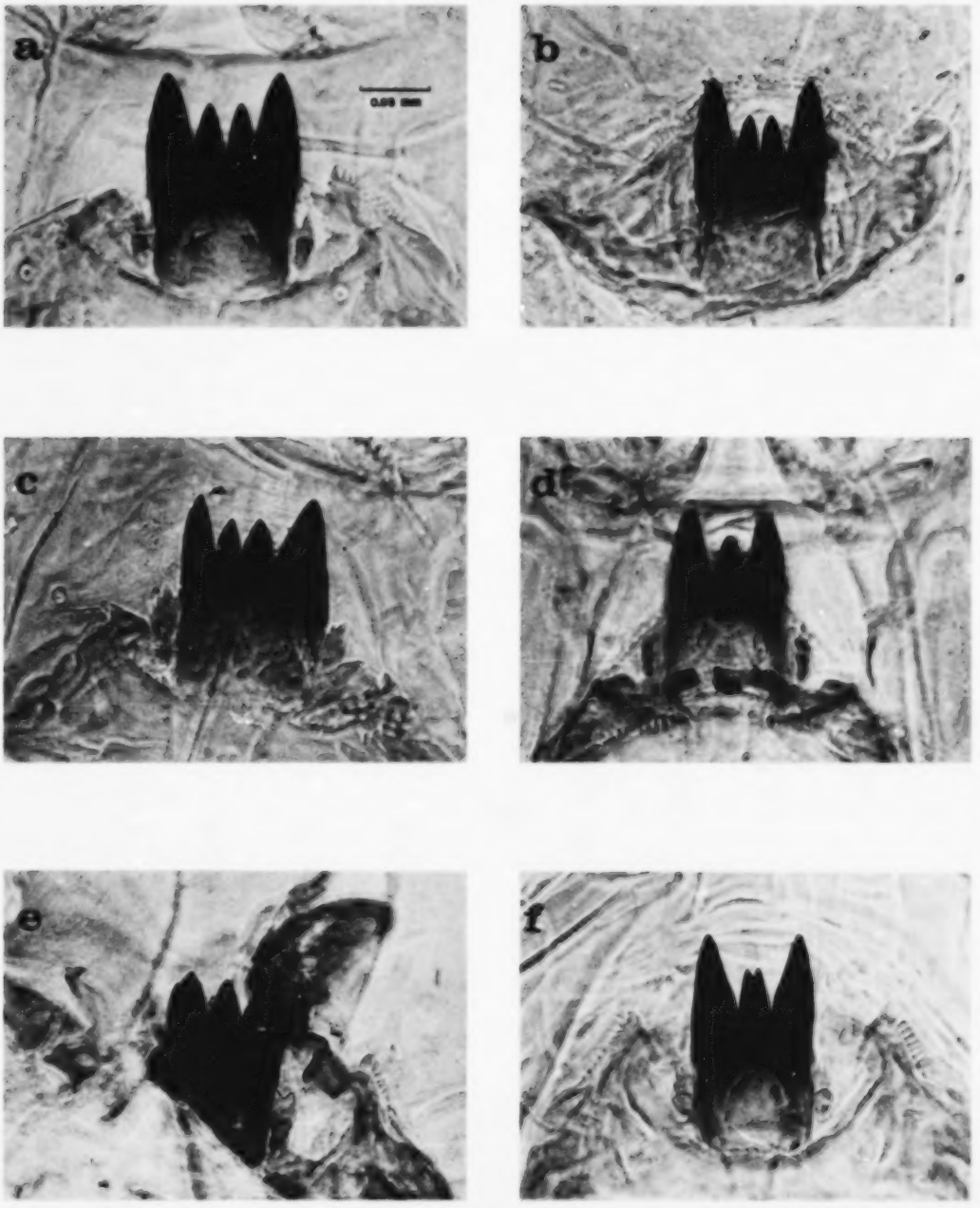

Figure 18. Variation in the shape of the ligula of Djalmabatista pulcher larvae collected in Marion County, Alabama.

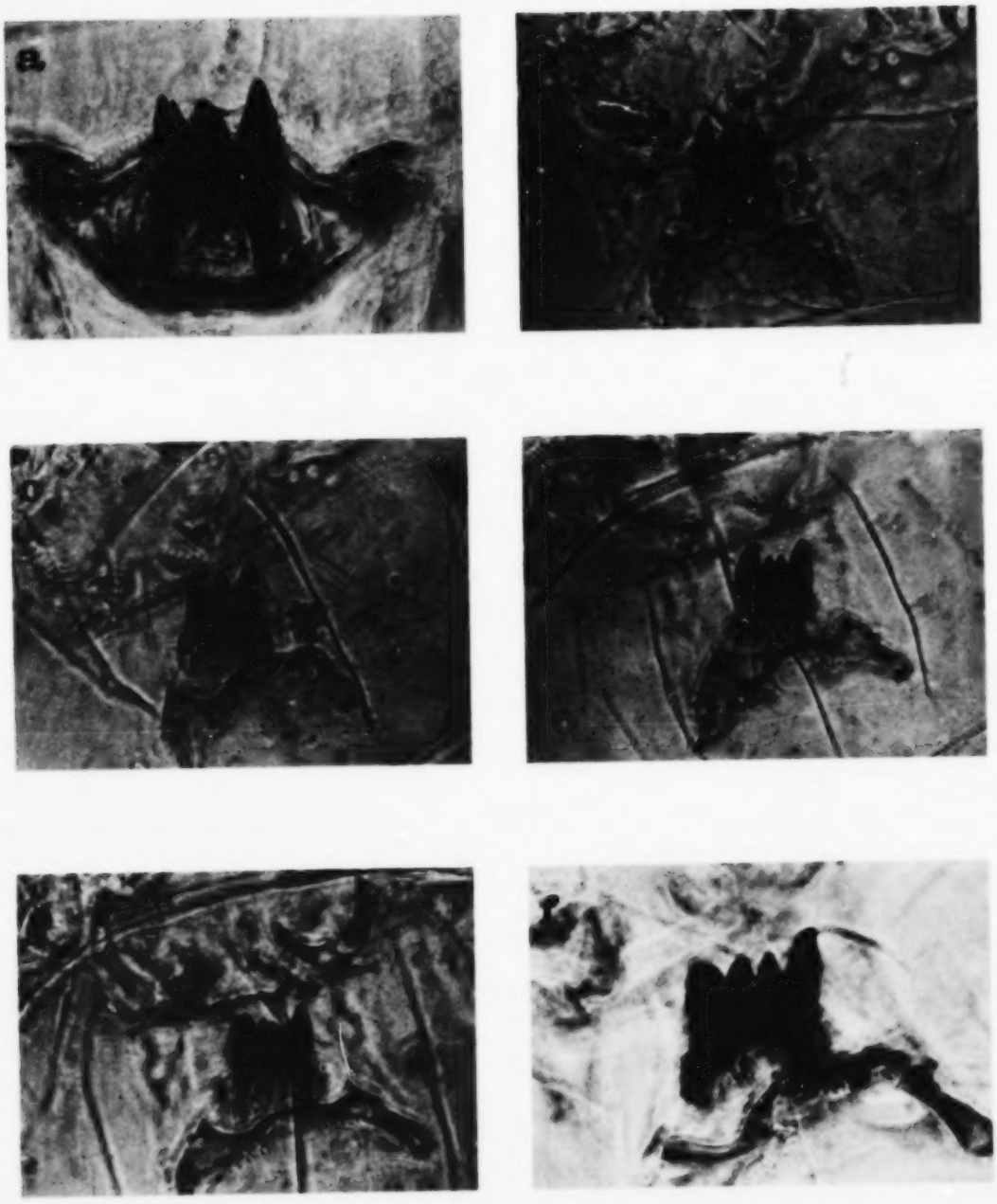

Figure 19. Variation in the shape of the ligula of Djalmabatista pulcher larvae collected in Marion County, Alabama.

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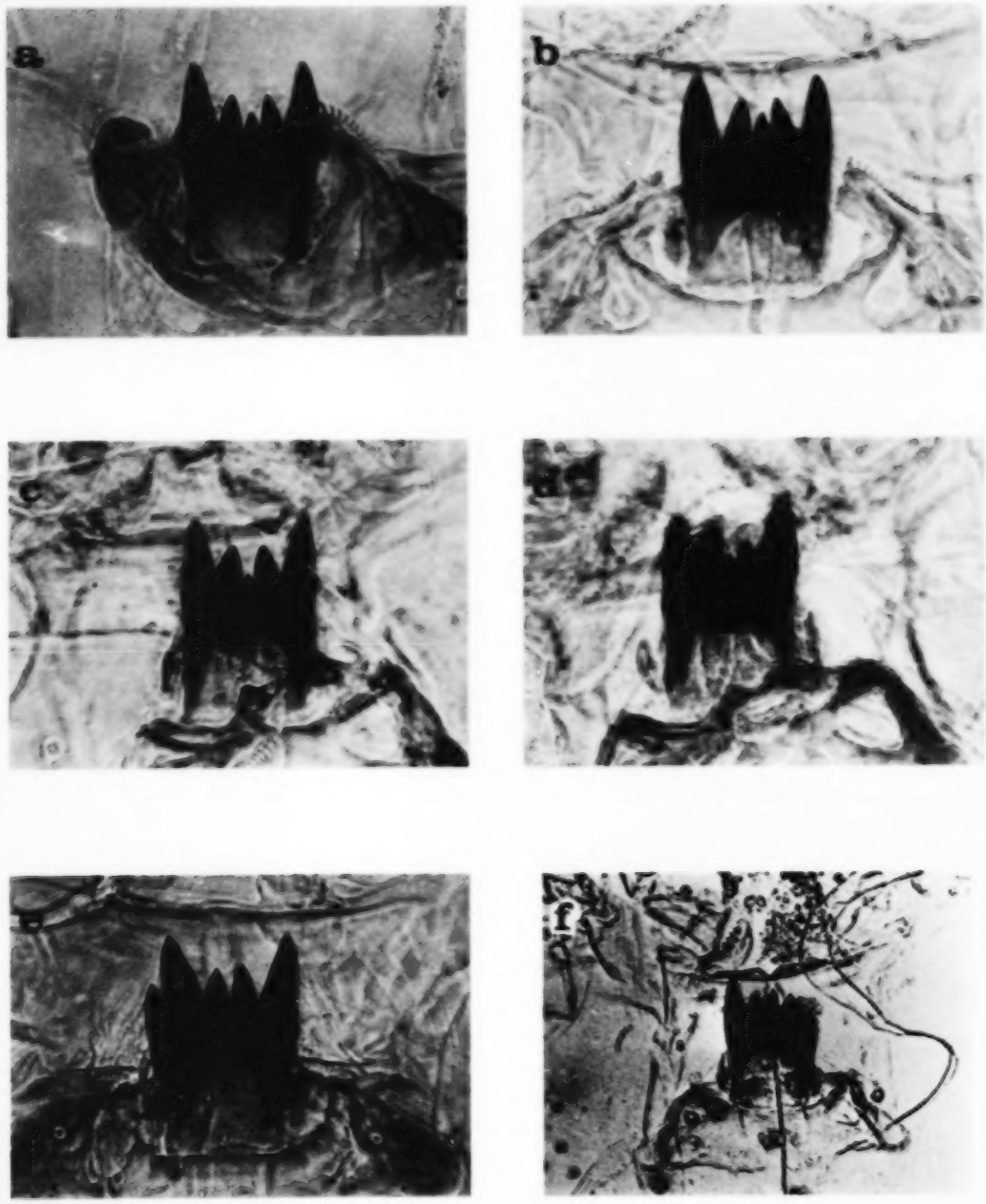

Figure 20. Variation in the shape of the ligula of Djalmabatista pulcher larvae collected in Marion County, Alabama.

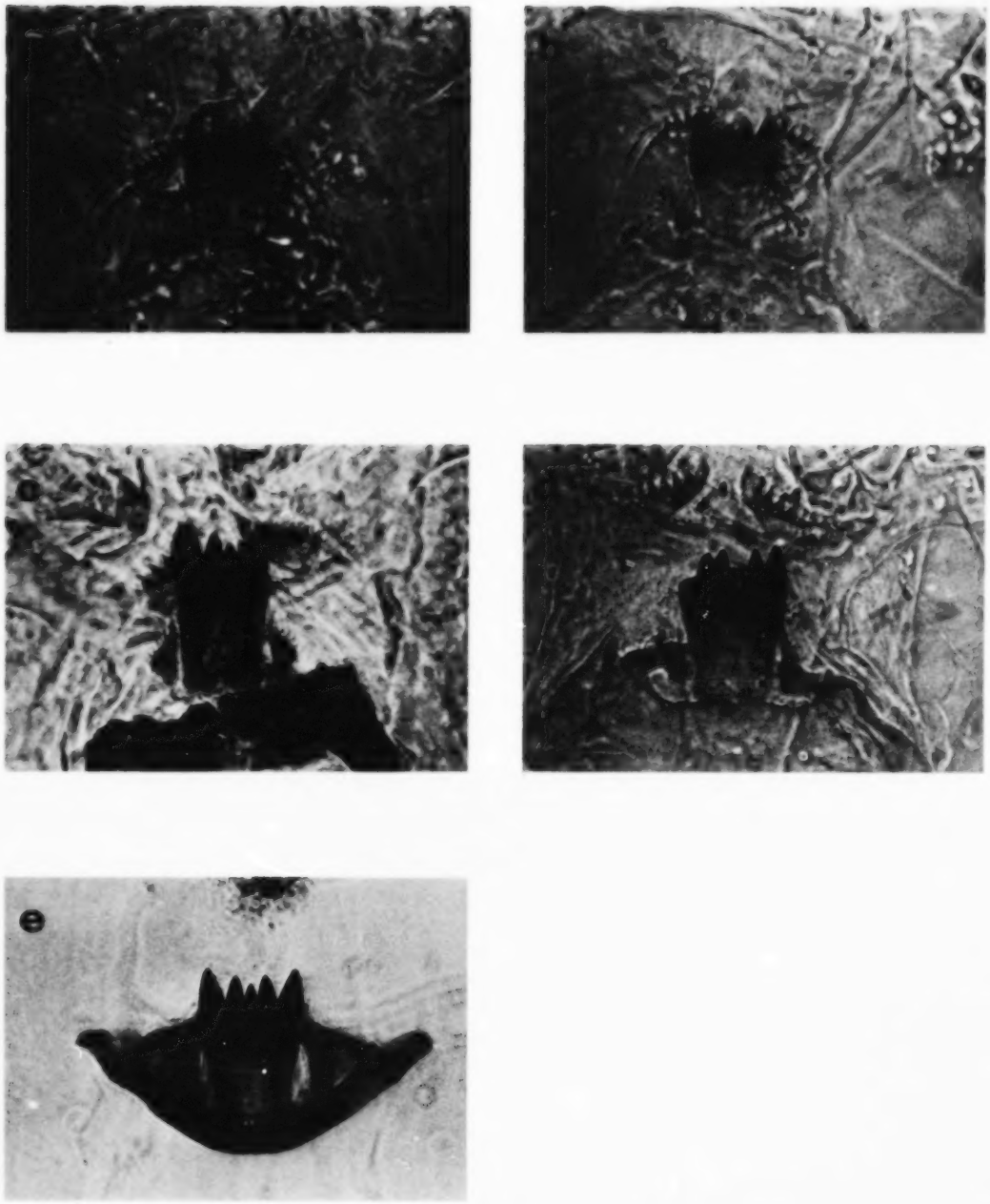

Figure 21. Variation in the shape of the ligula of Procladius bellus larvae from Buttahatchee Lake, Alabama.

TABLE 6. CLASSIFICATION OF THE DIFFERENT TYPES OF LIGULA ABNORMALITIES AND THE FREQUENCY OF EACH TYPE FOUND IN LARVAE OF D. PULCHER

Pond	4 Teeth		3 Teeth			5 Teeth	
	Asym.	Curved	Sym.	Asym.	Bifid	Sym.	Asym.
1						4	
4	6	3	1		3	5	1
5	4	1	5	2		3	2
M.C.L.	1		4		2	1	2

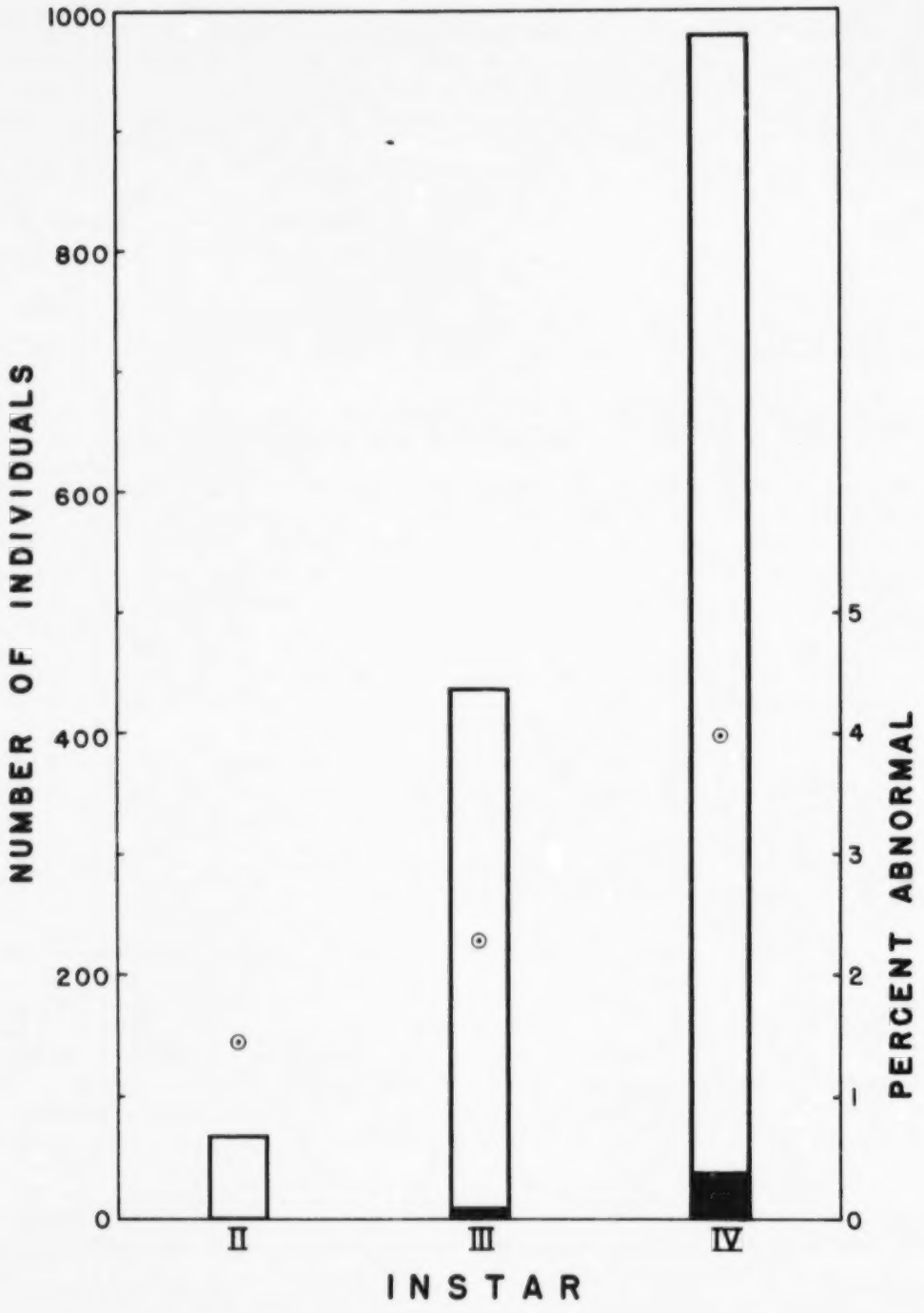

Figure 22. Number of larvae of D. pulcher (clear bars) and the number of abnormal individuals (black bars), along with the corresponding percentages of abnormalities (points) in instars II-IV.

The number of D. pulcher larvae possessing an abnormal ligula and the corresponding percentage are given in Table 7 for each of the strip mine ponds, and for the strip mine ponds combined, and for Marion County Lake. Unfortunately, the late discovery of the D. pulcher population at Marion County Lake did not allow a comparison of the percentages for the entire sampling period. Therefore, only the data from June to October were used to test for significance of difference between the strip mine ponds and Marion County Lake. These data were arranged in the following 2 x 2 contingency table and chi-square was calculated using Yates' correction for continuity.

	Number of Abnormal Ligulas	Number of Normal Ligulas
Strip mine ponds	12	383
Marion County Lake	10	532

The probability of a chi-square value larger than that calculated (0.946) was 0.36. Therefore, the proportions are not significantly different.

Because of the scarcity of information on the "natural" or background incidence of morphological abnormalities in other populations of D. pulcher or in other species of Chironomidae, no comparison with the 1.85% incidence in the D. pulcher samples from our reference site, Marion County Lake, can be made. It is possible that some combination of undetermined factors common to this region of northern Alabama is responsible for the similar frequencies of abnormalities found in the strip mine ponds and Marion County Lake. An examination of the 223 larvae of Procladius bellus (Loew) collected in Buttahatchee Lake during this study revealed 10 ligula abnormalities, some of which are shown in Figures 21a-d, as compared to a normal ligula of P. bellus shown in Figure 21e. This percentage (4.5%) is higher than the combined percentage for D. pulcher larvae from the strip mine ponds. In light of this information, characterization of populations of D. pulcher and P. bellus in other parts of their geographic ranges is highly desirable. To our knowledge, abnormal ligulas have not been reported in P. bellus, a common and widely distributed species.

Because the incidence of abnormalities in D. pulcher from the strip mine ponds was not significantly different from the incidence in Marion County Lake, we did not think it justifiable to attempt to induce abnormalities in the laboratory using strip mine pond water. Attempts to pinpoint causative factors based on such low responses as obtained from the field samples would be difficult and probably inconclusive. Furthermore, not enough data could be gathered at this rate for a reliable assessment of the longevity and successful development of abnormal larvae. We did apply a series of regression equations matching selected water quality parameters, diversity index values, and monthly sample size with the percentages of abnormalities at each site. None of these variables taken individually significantly explained the variation in the frequency of abnormalities.

TABLE 7. INCIDENCE OF LIGULA ABNORMALITIES (NO. ABNORMAL/TOTAL NO.) IN LARVAE OF D. PULCHER COLLECTED IN MARION COUNTY, ALABAMA, 1978

Site	Mar 1	Mar 28	Apr 27	May 24	Total	Jun 20	Jul 18	Aug 15	Sep 12	Oct 17	Total
Strip Mine Pond #1	1/4	2/6	0/1	1/3	4/14	0	0/1	0/4	0/1	0	0/6
Strip Mine Pond #4	3/47	0/68	5/204	7/146	15/465	1/64	1/20	1/29	0/13	1/30	4/156
Strip Mine Pond #5	0/16	1/11	6/90	2/12	9/129	1/23	2/27	1/42	0/16	4/125	8/233
Strip Mine Ponds Total	4/67	3/85	11/295	10/161	28/608 =4.61%	2/87	3/48	2/75	0/30	5/155	12/395 =3.04%
Marion County Lake	-	-	-	-		Jun 15 2/143	1/104	4/78	1/74	2/143	10/542 =1.85%

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APPENDIX

Tables A-1 to A-4

Physicochemical Measurements

TABLE A-1 PHYSICOCHEMICAL MEASUREMENTS OF STRIP MINE PONDS AND CONTROL LAKE IN MARION COUNTY, ALABAMA FROM JANUARY 30 TO FEBRUARY 10, 1978

Location	Statistic	Constituent (mg/l)								
		Dissolved Solids	Suspended Solids	Sulfate (SO4)	Calcium	Magnesium	Ca-Mg Hardness	Manganese	Dissolved Iron	Total Iron
Pond 1	Mean	81.7	18.8	33.8	7.9	8.6	55.2	.03	.05	.92
	95% C.L.	4.3	7.6	1.5	1.2	1.4	6.4	.01	0	.79
	Range	80 - 90	14 - 33	32 - 36	6.4 - 8.8	6.2 - 9.7	47 - 62	.02 - .04	.05	.38 - 2.4
Pond 2	Mean	301.7	4.0	165.0	38.7	22.5	188.3	0.21	0.05	0.12
	95% C.L.	61.4	1.8	29.5	13.9	14.7	52.0	0.10	0	0.17
	Range	220 - 360	2.0 - 6.0	120 - 190	22.0 - 58.0	6.0 - 39.0	140.0 - 260.0	0.09 - 0.35	0.05	.05 - 0.49
Pond 3	Mean	81.5	11.3	49.8	6.9	7.2	46.5	0.98	0.05	0.33
	95% C.L.	11.9	5.8	3.7	1.3	0.8	4.7	0.11	0	0.23
	Range	70.0 - 99.0	5.0 - 19.0	45.0 - 55.0	5.5 - 8.6	6.3 - 8.0	41.0 - 53.0	0.84 - 1.10	0.05	0.10 - 0.73
Pond 4	Mean	73.3	12.5	45.5	12.1	5.9	54.2	0.13	0.06	1.14
	95% C.L.	34.9	3.8	18.1	17.0	0.8	44.2	0.03	0.03	0.69
	Range	50.0 - 140.0	9.0 - 19.0	35.0 - 80.0	4.3 - 45.0	4.9 - 7.0	34.0 - 140.0	0.10 - 0.18	0.05 - 0.12	0.50 - 2.20
Pond 5	Mean	121.7	8.8	80.1	10.4	14.2	83.8	0.78	0.05	0.37
	95% C.L	10.3	4.5	4.7	2.3	2.1	10.3	0.11	0	0.15
	Range	110.0 - 140.0	6.0 - 17.0	72.0 - 84.0	8.2 - 14.0	13.0 - 18.0	74.0 - 100.0	0.67 - 0.92	0.05	0.17 - 0.52
Pond 6	Mean	63.3	8.7	36.5	5.5	5.5	35.5	0.44	0.05	0.39
	95% C.L.	5.4	4.3	6.3	0.8	0.5	1.9	0.02	0	0.20
	Range	60.0 - 70.0	1.0 - 13.0	25.0 - 41.0	4.9 - 6.8	4.0 - 6.1	34.0 - 38.0	0.42 - 0.46	0.05	0.14 - 0.68
Buttahatchee Lake	Mean	23.3	13.0	4.5	3.6	1.2	13.5	0.20	0.16	0.68
	95% C.L	8.6	8.9	2.0	4.9	0.3	13.2	0.12	0.16	0.20
	Range	10.0 - 30.0	4.0 - 25.0	1.0 - 6.0	1.0 - 13.0	1.0 - 1.7	7.0 - 39.0	0.08 - 0.34	0.05 - 0.44	0.50 - 0.95

TABLE A-1 (continued)

Location	Statistic	Constituent (mg/l) Conductivity (μmhos cm^{-1})	Total Alkalinity	Acidity	pH (s.u.)	Dissolved Oxygen	Nitrogen (Kjeldahl)	Phosphates	Total Carbon	Temperature °C
Pond 1	Mean	74.8	29.8	1.4	7.3	11.9	.137	0.01	0.80	2.4
	95% C.L.	4.5	2.2	0.5		0.3	.083	0.01	0.36	1.3
	Range	70 - 80	26 - 32	1 - 2	7.2 - 7.4	11.6 - 12.2	.040 - .26	0.01 - 0.02	0.20 - 1.20	1.0 - 3.8
Pond 2	Mean	245.2	64.2	2.4	7.4	12.8	0.075	0.01	0.85	1.1
	95% C.L	55.1	10.0	1.0		0.9	0.070	0.01	0.60	1.2
	Range	170 - 310	52 - 72	1.0 - 3.0	7.2 - 7.6	11.8 - 14.3	0.02 - 0.20	0.01 - 0.02	0.20 - 1.90	0 - 2.8
Pond 3	Mean	90.8	3.2	2.5	5.9	11.4	0.157	0.02	1.70	2.9
	95% C.L.	30.2	3.7	0.6		0.5	0.10	0.01	0.42	0.8
	Range	65.0 - 188.0	1.0 - 10.0	2.0 - 3.0	5.7 - 6.0	10.7 - 12.1	0.04 - 0.30	0.01 - 0.02	1.30 - 2.40	2.0 - 3.8
Pond 4	Mean	63.5	1.3	2.3	5.7	11.7	0.112	0.02	1.75	2.8
	95% C.L.	10.9	0.5	0.9		1.1	0.070	0.01	0.40	1.1
	Range	50.0 - 80.0	1.0 - 2.0	1.0 - 3.0	5.6 - 5.8	10.4 - 13.2	0.060 - 0.240	0.01 - 0.03	1.40 - 2.40	1.2 - 4.0
Pond 5	Mean	119.7	1.4	2.5	6.1	12.0	0.090	0.01	0.45	3.3
	95% C.L.	5.0	0.6	2.0		0.3	0.051	0.0	0.48	1.1
	Range	113.0 - 125.0	1.0 - 2.5	1.0 - 6.0	6.0 - 6.2	11.8 - 12.6	0.04 - 0.18	0.01 - 0.02	0.0 - 1.20	1.5 - 4.5
Pond 6	Mean	61.3	1.3	1.3	5.7	12.0	0.125	0.01	1.05	3.9
	95% C.L.	1.7	0.4	0.5		0.3	0.123	0.01	1.33	0.8
	Range	59.0 - 63.0	1.0 - 2.0	1.0 - 2.0	5.6 - 6.0	11.6 - 12.3	0.03 - 0.32	0.01 - 0.02	0.20 - 3.60	2.6 - 4.5
Buttahatchee Lake	Mean	20.8	7.8	2.5	6.4	11.8	0.058	0.01	0.68	2.3
	95% C.L	3.1	4.2	1.1		0.8	0.034	0.01	0.32	0.6
	Range	18.0 - 26.0	4.0 - 13.0	1.0 - 4.0	6.1 - 6.6	10.6 - 12.8	0.030 - 0.100	0.01 - 0.02	0.20 - 1.10	1.5 - 3.1

TABLE A-2 PHYSICOCHEMICAL MEASUREMENTS OF STRIP MINE PONDS AND CONTROL LAKE IN MARION COUNTY, ALABAMA FROM APRIL 17 to APRIL 28, 1978

Location	Statistic	Constituent (mg/l) Dissolved Solids	Suspended Solids	Sulfate (SO4)	Calcium	Magnesium	Ca-Mg Hardness	Manganese	Dissolved Iron	Total Iron
Pond 1	Mean	83.3	18.0	36.1	9.6	9.4	62.3	0.03	0.09	0.43
	95% C.L.	5.4	13.8	2.6	1.7	1.0	7.3	0.04	0.17	0.37
	Range	80.0 - 90.0	5.0 - 39.0	33.0 - 40.0	8.0 - 12.0	7.5 - 10.0	51.0 - 70.0	0.01 - 0.10	0.01 - 0.41	0.20 - 1.10
Pond 2	Mean	465.0	4.3	253.3	64.2	56.3	390.0	0.07	0.03	0.14
	95% C.L.	19.6	1.7	28.7	22.0	16.9	104.5	0.01	0.02	0.08
	Range	450 - 500	2.0 - 6.0	230.0 - 290.0	43.0 - 96.0	48.0 - 89.0	310.0 - 570.0	0.05 - 0.08	0.01 - 0.0[illegible]	0.07 - 0.29
Pond 3	Mean	90.0	9.7	56.3	6.9	7.8	49.2	0.86	0.04	0.20
	95% C.L.	5.1	8.1	5.7	1.0	0.6	3.5	0.01	0.01	0.19
	Range	80.0 - 100.0	5.0 - 25.0	48.0 - 64.0	5.5 - 8.1	6.9 - 8.3	43.0 - 52.0	0.84 - 0.87	0.02 - 0.05	0.07 - 0.57
Pond 4	Mean	136.7	8.8	88.3	13.0	13.4	88.5	0.76	0.08	0.19
	95% C.L.	31.6	3.4	19.6	3.3	4.3	26.0	0.55	0.04	0.05
	Range	100.0 - 170.0	6.0 - 15.0	66.0 - 110.0	9.5 - 17.0	9.0 - 19.0	61.0 - 120.0	0.37 - 1.50	0.04 - 0.12	0.15 - 0.24
Pond 5	Mean	160.0	15.2	104.2	13.2	21.8	121.7	0.[illegible]	0.03	0.35
	95% C.L.	9.4	10.1	7.0	0.8	8.5	36.0	[illegible]	0.03	0.24
	Range	150.0 - 170.0	4.0 - 31.0	95.0 - 110.0	12.0 - 14.0	17.0 - 38.0	100.0 - 190.0	0.71 - 0.80	0.01 - 0.05	0.11 - 0.71
Pond 6	Mean	66.7	10.2	35.7	6.4	5.8	40.2	0.56	0.03	0.30
	95% C.L.	5.4	6.3	15.6	1.6	0.5	5.5	0.03	.02	0.19
	Range	60.0 - 70.0	6.0 - 22.0	6.0 - 45.0	4.5 - 8.8	5.1 - 6.4	32.0 - 47.0	0.51 - 0.58	0.01 - 0.05	0.12 - 0.63
Buttahatchee Lake	Mean	40.0	12.7	4.0	2.6	1.4	12.3	0.22	0.22	0.79
	95% C.L.	16.3	5.4	2.3	0.4	0.1	1.3	0.05	0.04	0.17
	Range	30.0 - 70.0	6.0 - 20.0	2.0 - 8.0	2.0 - 3.1	1.3 - 1.5	11.0 - 14.0	0.15 - 0.26	0.15 - 0.25	0.63 - 1.10

TABLE A-2 (continued)

Location	Statistic	Constituent (mg/l) Conductivity (μmhos cm^{-1})	Total Alkalinity	Acidity	pH (s.u.)	Dissolved Oxygen	Nitrogen (Kjeldahl)	Phosphates	Total Carbon	Temperature °C
Pond 1	Mean	122.8	25.0	4.3	7.0	8.6	0.15	0.13	1.72	17.7
	95% C.L.	5.2	5.9	1.1		0.4	0.05	0.01	1.[illegible]	2.4
	Range	118.0 - 130.0	16.0 - 30.0	3.0 - 6.0	6.7 - 7.7	8.2 - 9.0	0.10 - 0.20	0.10 - 0.20	0.50 - 3.30	14.0 - 20.0
Pond 2	Mean	556.0	93.2	4.3	7.4	8.3	0.12	0.01	1.05	17.0
	95% C.L.	35.2	4.6	2.9		0.2	0.04	0	0.60	2.6
	Range	58.0 - 600.0	88.0 - 99.0	2.0 - 9.0	7.2 - 7.8	8.1 - 8.7	0.09 - 0.18	0.01	0.20 - 1.90	14.0 - 19.0
Pond 3	Mean	176.8	36.0	2.7	5.8	8.5	0.11	0.01	1.70	17.1
	95% C.L.	155.9	10.3	1.6		0.3	0.03	0.00	1.26	2.1
	Range	110.0 - 480.0	30.0 - 50.0	1.0 - 4.0	5.3 - 6.1	8.0 - 8.8	0.08 - 0.16	0.01 - 0.02	0.40 - 3.30	14.0 - 19.5
Pond 4	Mean	166.7	30.0	2.8	5.3	8.9	0.18	0.02	3.20	18.2
	95% C.L.	25.3	18.2	1.9		0.4	0.05	0.01	1.08	3.3
	Range	141.0 - 208.0	10.0 - 50.0	1.0 - 5.0	5.0 - 5.7	8.2 - 9.5	0.13 - 0.24	0.01 - 0.03	1.40 - 4.10	15.0 - 23.0
Pond 5	Mean	216.8	10.0	3.2	5.3	8.1	0.25	0.03	0.68	17.8
	95% C.L.	12.5	0.0	1.0		0.3	0.21	0.02	0.69	2.6
	Range	200.0 - 235.0	10.0	2.0 - 4.0	5.1 - 5.7	7.5 - 8.3	0.08 - 0.58	0.01 - 0.06	0.20 - 1.80	14.0 - 21.0
Pond 6	Mean	97.0	36.0	3.3	5.6	8.0	0.11	0.02	0.40	20.0
	95% C.L.	1.9	43.5	0.5		0.3	0.03	0.01	0.42	4.8
	Range	95.0 - 99.0	10.0 - 100.0	3.0 - 4.0	5.3 - 5.9	7.6 - 8.3	0.9 - 0.16	0.01 - 0.04	0.20 - 1.20	16.0 - 28.8
Buttahatchee Lake	Mean	41.0	48.0	2.8	6.3	8.2	0.17	0.01	1.8	18.0
	95% C.L.	21.4	46.3	0.8		0.4	0.05	0.0	0.5	1.8
	Range	30.0 - 82.0	10.0 - 90.0	2.0 - 4.0	6.0 - 6.9	7.7 - 8.7	0.11 - 0.24	0.01 - 0.02	0.9 - 2.4	15.0 - 20.0

TABLE A-3 PHYSIOCOCHEMICAL MEASUREMENTS OF STRIP MINE PONDS AND CONTROL LAKES IN MARION COUNTY, ALABAMA FROM JULY 10 to JULY 21, 1978

Location	Statistic	Constituent (mg/l) Dissolved Solids	Suspended Solids	Sulfate (SO4)	Calcium	Magnesium	Ca-Mg Hardness	Manganese	Dissolved Iron	Total Iron
Pond 1	Mean	125.0	34.3	44.0	9.7	10.2	65.8	0.05	0.05	0.96
	95% C.L.	66.0	40.8	9.8	0.5	0.7	3.2	0.04	0	1.13
	Range	80.0 - 250.0	3.0 - 110.0	35.0 - 62.0	8.8 - 10.0	9.8 - 11.0	62.0 - 70.0	0.01 - 0.11	0.05	0.12 - 3.10
Pond 2	Mean	383.3	5.8	223.3	45.2	42.0	286.7	0.08	0.05	0.15
	95% C.L.	8.6	4.8	23.6	8.3	1.2	22.7	0.03	0	0.14
	Range	370.0 - 390.0	1.0 - 12.0	200.0 - 260.0	35.0 - 58.0	41.0 - 44.0	260.0 - 320.0	0.05 - 0.11	0.05	0.05 - 0.37
Pond 3	Mean	88.3	27.8	55.5	7.2	7.2	47.3	0.68	0.05	0.50
	95% C.L.	12.3	10.6	6.7	0.9	0.4	3.9	0.05	0	0.14
	Range	70.0 - 100.0	18.0 - 43.0	50.0 - 68.0	5.5 - 7.8	6.4 - 7.6	40.0 - 50.0	0.64 - 0.74	0.05	0.40 - 0.75
Pond 4	Mean	105.0	19.7	64.5	8.0	9.1	59.2	0.47	0.05	0.52
	95% C.L.	14.5	19.7	12.9	1.4	1.7	10.5	0.18	0.0	0.46
	Range	90.0 - 130.0	2.0 - 46.0	45.0 - 81.0	6.3 - 10.0	7.4 - 12.0	46.0 - 74.0	0.17 - 0.63	0.05	0.14 - 1.30
Pond 5	Mean	96.7	18.7	69.2	8.3	9.1	57.8	0.26	0.05	0.54
	95% C.L.	5.4	15.9	6.5	0.7	0.6	3.4	0.12	0.0	0.54
	Range	90.0 - 100.0	3.0 - 44.0	60.0 - 78.0	7.8 - 9.5	8.2 - 9.9	55.0 - 64.0	0.07 - 0.39	0.05	0.10 - 1.50
Pond 6	Mean	73.3	5.2	42.8	6.2	6.2	41.0	0.85	0.05	0.19
	95% C.L.	8.6	5.5	10.7	1.1	0.4	4.1	0.04	0.0	0.13
	Range	60.0 - 80.0	1.0 - 15.0	23.0 - 51.0	5.1 - 7.6	5.6 - 6.8	36.0 - 46.0	0.82 - 0.90	0.05	0.07 - 0.40
Buttahatchee Lake	Mean	38.3	12.3	6.0	3.5	2.0	16.8	0.43	0.32	1.14
	95% C.L.	12.3	4.0	3.0	0.7	0.2	2.3	0.25	0.05	0.22
	Range	20.0 - 50.0	10.0 - 20.0	1.0 - 9.0	2.7 - 4.3	1.7 - 2.2	14.0 - 20.0	0.19 - 0.86	0.26 - 0.39	0.94 - 1.50
Marion Co. Lake	Mean	23.3	9.8	2.7	1.6	0.6	6.2	0.06	0.05	0.23
	95% C.L.	12.7	3.9	1.4	0.3	0.1	1.0	0.02	0.0	0.07
	Range	10.0 - 40.0	5.0 - 15.0	1.0 - 5.0	1.2 - 2.0	0.5 - 0.7	5.0 - 7.0	.04 - .09	0.05	0.14 - 0.32

TABLE A-3 (continued)

Location	Statistic	Constituent (mg/l) Conductivity (μmhos cm^{-1})	Total Alkalinity	Acidity	pH (s.u.)	Dissolved Oxygen	Nitrogen (Kjeldahl)	Phosphates	Total Carbon	Temperature °C
Pond 1	Mean	140.8	34.3	3.6	6.8	8.8	0.29	0.02	1.48	30.3
	95% C.L.	39.9	5.0	4.1		0.4	0.29	0.02	0.70	1.3
	Range	85.0 - 170.0	30.0 - 43.0	1.0 - 8.0	6.4 - 7.8	8.3 - 9.5	0.10 - 0.80	0.01 - 0.06	0.60 - 2.10	29.0 - 32.0
Pond 2	Mean	593.3	69.5	2.8	6.9	9.4	0.24	0.01	1.93	30.6
	95% C.L.	297.4	4.6	1.0		0.5	0.14	0	1.09	0.7
	Range	310.0 - 1100.0	62.0 - 75.0	2.0 - 4.0	6.6 - 7.3	8.8 - 10.0	0.11 - 0.40	0.01	0.90 - 3.90	30.0 - 31.5
Pond 3	Mean	117.3	2.7	1.8	6.0	9.8	0.29	0.02	4.35	30.5
	95% C.L.	32.0	2.0	0.5		0.1	0.17	0.01	1.12	1.2
	Range	72.0 - 140.0	1.0 - 6.0	1.0 - 2.0	5.4 - 8.0	9.6 - 10.0	0.15 - 0.58	0.01 - 0.04	26 - 56	29.0 - 32.0
Pond 4	Mean	139.2	2.0	3.0	5.5	9.7	0.32	0.02	3.5	29.3
	95% C.L.	30.2	0.9	0.8		1.4	0.22	0.01	1.3	0.9
	Range	92.0 - 160.0	1.0 - 3.0	2.0 - 4.0	5.1 - 6.6	7.5 - 11.6	0.16 - 0.68	0.01 - 0.04	2.4 - 5.3	28.0 - 30.5
Pond 5	Mean	212.5	2.7	3.4	6.1	8.9	0.23	0.02	1.72	31.5
	95% C.L.	192.3	1.3	2.7		0.3	0.22	0.02	0.34	1.5
	Range	95.0 - 580.0	1.0 - 4.0	1.0 - 7.0	5.6 - 7.4	8.5 - 9.3	0.10 - 064	0.01 - 0.05	1.40 - 2.30	30.0 - 33.0
Pond 6	Mean	154.8	1.5	3.0	5.6	8.8	0.20	0.02	1.58	31.3
	95% C.L.	130.1	0.9	0.0		0.1	0.14	0.01	0.71	0.86
	Range	62.0 - 400.0	1.0 - 3.0	3.0	5.0 - 6.4	8.5 - 8.8	0.08 - 0.38	0.01 - 0.04	0.90 - 2.80	30.0 - 32.0
Buttahatchee	Mean	45.0	10.5	3.6	6.3	9.6	0.22	0.01	3.62	31.4
	95% C.L.	10.5	2.0	1.7		0.6	0.09	0.0	0.34	1.7
	Range	30.0 - 55.0	8.0 - 13.0	2.0 - 6.0	5.9 - 7.2	8.8 - 10.4	0.10 - 0.30	0.01	3.20 - 4.10	29.0 - 33.0
Marion Co. Lake	Mean	18.7	1.5	2.4	6.1	9.8	0.43	0.19	3.9	32.3
	95% C.L.	5.6	0.6	0.8		0.6	0.11	0.06	1.0	0.5
	Range	10.0 - 25.0	1.0 - 2.0	2.0 - 3.0	5.5 - 6.8	9.4 - 10.8	0.30 - 0.54	0.12 - 0.25	3.1 - 5.7	32.0 - 33.0

TABLE A-4 PHYSIOCOCHEMICAL MEASUREMENTS OF STRIP MINE PONDS AND CONTROL LAKES IN MARION COUNTY, ALABAMA FROM OCTOBER 16 TO OCTOBER 27, 1978

Location	Statistic	Constituent (mg/l)								
		Dissolved Solids	Suspended Solids	Sulfate (SO4)	Calcium	Magnesium	Ca-Mg Hardness	Manganese	Dissolved Iron	Total Iron
Pond 1	Mean	116.7	3.2	49.5	12.8	13.8	88.8	0.02	0.06	0.08
	95% C.L.	5.4	1.2	2.6	1.7	1.7	6.6	0.01	0.02	0.05
	Range	110.0 - 120.0	2.0 - 5.0	47.0 - 54.0	11.0 - 15.0	11.0 - 16.0	78.0 - 95.0	0.01 - 0.02	0.05 - 0.09	0.05 - 0.15
Pond 2	Mean	505.0	3.0	313.3	51.8	58.0	366.7	0.05	0.06	0.14
	95% C.L.	11.0	1.8	19.5	11.9	8.1	61.8	0.08	0.01	0.11
	Range	490.0 - 520.0	1.0 - 5.0	300.0 - 350.0	41.0 - 74.0	53.0 - 72.0	320.0 - 480.0	0.01 - 0.20	0.05 - 0.07	0.05 - 0.29
Pond 3	Mean	103.3	12.2	62.8	8.3	8.1	54.0	0.99	0.51	2.03
	95% C.L.	8.6	4.8	7.7	0.7	0.4	1.6	0.01	0.48	1.08
	Range	100.0 - 120.0	8.0 - 19.0	56.0 - 74.0	7.1 - 8.9	7.6 - 8.7	52.0 - 56.0	0.97 - 1.00	0.08 - 0.96	1.20 - 3.40
Pond 4	Mean	268.3	26.5	183.3	24.2	25.3	165.0	1.95	0.07	0.40
	95% C.L.	25.2	43.5	18.4	5.5	2.9	23.7	0.39	0.03	0.28
	Range	230.0 - 290.0	2.0 - 110.0	160.0 - 210.0	18.0 - 31.0	21.0 - 29.0	140.0 - 200.0	1.30 - 2.30	0.05 - 0.13	0.14 - 0.72
Pond 5	Mean	141.7	11.8	97.5	12.5	14.5	90.5	0.31	0.06	0.53
	95% C.L.	4.3	9.2	8.0	1.1	0.9	3.2	0.03	0.01	0.19
	Range	140.0 - 150.0	2.0 - 28.0	87.0 - 110 0	11.0 - 14.0	14.0 - 16.0	87.0 - 94.0	0.28 - 0.36	0.05 - 0.08	0.27 - 0.80
Pond 6	Mean	100.0	16.0	67.5	8.8	8.2	55.5	1.12	0.05	0.54
	95% C.L.	0.0	13.2	7.6	0.7	0.3	1.6	0.04	0.00	0.54
	Range	100.0	3.0 - 34.0	61.0 - 80.0	7.8 - 9.4	7.8 - 8.5	53.0 - 57.0	1.10 - 1.20	0.05 - 0.06	0.16 - 1.30
Buttahatchee Lake	Mean	43.3	21.7	17.0	4.3	2.5	21.2	0.20	0.21	1.22
	95% C.L.	5.4	10.6	2.7	0.58	0.1	1.4	0.02	0.07	0.38
	Range	40.0 - 50.0	7.0 - 34.0	15.0 - 22.0	3.4 - 4.9	2.5 - 2.6	19.0 - 23.0	0.18 - 0.23	0.10 - 0.28	0.71 - 1.60
Marion Co. Lake	Mean	23.3	9.0	2.8	1.8	0.70	7.3	0.20	0.08	0.30
	95% C.L.	8.6	5.1	1.03	0.4	0.09	1.3	0.10	0.03	0.15
	Range	10.0 - 30.0	4.0 - 16.0	1.0 - 4.0	1.1 - 2.1	0.60 - 0.80	5.0 - 8.0	0.03 - 0.29	0.05 - 0.12	0.12 - 0.45

TABLE A-4 (continued)

Location	Statistic	Constituent (mg/l) Conductivity (μmhos cm^{-1})	Total Alkalinity	Acidity	pH (s.u.)	Dissolved Oxygen	Nitrogen (Kjeldahl)	Nitrates-Nitrites	Phosphates	Total Carbon	Temperature °C
Pond 1	Mean	201.7	36.5	1.6	6.8	11.0	0.11	0.01	0.01	1.97	17.8
	95% C.L.	42.3	4.1	0.8		1.4	0.06	0.0	0.0	0.31	0.6
	Range	130.0 - 255.0	32.0 - 42.0	1.0 - 3.0	6.5 - 7.3	9.2 - 12.0	0.04 - 0.22	0.01	0.01	16.0 - 2.40	17.0 - 18.5
Pond 2	Mean	660.0	65.3	2.0	7.1	11.5	0.09	0.02	0.01	1.45	15.0
	95% C.L.	125.3	5.4	1.6		1.6	0.05	0.01	0.0	0.26	0.9
	Range	420.0 - 740.0	60.0 - 75.0	1.0 - 5.0	6.8 - 7.8	9.6 - 12.7	0.01 - 0.12	0.01 - 0.04	0.01	1.10 - 1.80	14.0 - 16.0
Pond 3	Mean	158.8	10.0	2.0	6.1	11.2	0.11	0.02	0.02	4.92	15.7
	95% C.L.	33.9	3.2	0.6		1.6	0.02	0.01	0.01	1.21	0.2
	Range	100.0 - 190.0	6.0 - 15.0	1.2 - 3.0	5.8 - 6.4	9.0 - 12.6	0.08 - 0.14	0.01 - 0.04	0.01 - 0.03	3.3 - 6.5	14.0 - 17.0
Pond 4	Mean	389.2	4.2	2.8	5.3	11.0	0.12	0.01	0.02	3.08	11.5
	95% C.L.	88.1	1.4	0.8		1.0	0.03	0.0	0.01	0.47	2.2
	Range	230.0 - 450.0	2.0 - 5.0	2.0 - 4.0	5.0 - 5.8	9.5 - 11.5	0.08 - 0.17	0.01	0.01 - 0.03	2.60 - 3.80	9.0 - 14.0
Pond 5	Mean	229.2	3.0	3.0	5.3	11.1	0.12	0.04	0.04	2.90	17.2
	95% C.L.	43.7	0.9	0.9		1.3	0.01	0.02	0.02	0.29	1.1
	Range	145.0 - 255.0	2.0 - 4.0	2.0 - 4.0	5.1 - 5.8	9.3 - 12.0	0.10 - 0.13	0.03 - 0.07	0.03 - 0.07	2.50 - 3.30	16.0 - 19.0
Pond 6	Mean	175.0	2.7	3.3	5.4	11.4	0.09	0.07	0.01	1.47	17.8
	95% C.L.	36.5	0.9	1.3		1.5	0.01	0.01	0.0	0.55	1.0
	Range	105.0 - 195.0	2.0 - 4.0	2.0 - 5.0	5.0 - 6.2	9.2 - 12.6	0.08 - 0.10	0.05 - 0.09	0.01	1.00 - 2.40	16.0 - 19.0
Suttahatchee Lake	Mean	76.3	8.3	4.3	6.3	10.5	0.19	0.09	0.01	2.75	17.6
	95% C.L	14.6	2.2	1.7		1.8	0.05	0.02	0.00	0.36	0.8
	Range	50.0 - 90.0	6.0 - 12.0	2.0 - 6.0	5.8 - 6.7	8.2 - 12.1	0.12 - 0.27	0.07 - 0.12	0.01 - 0.02	2.4 - 3.4	17.0 - 18.5
Marion Co. Lake	Mean	25.8	4.5	3.3	6.3	10.8	0.26	0.02	0.15	4.63	20.3
	95% C.L.	6.1	2.0	1.8		1.7	0.04	0.01	0.04	0.37	1.13
	Range	20.0 - 35.0	2.0 - 7.0	1.0 - 6.0	5.8 - 6.8	8.8 - 12.8	0.20 - 0.31	0.01 - 0.02	0.12 - 0.20	4.20 - 5.20	19.0 - 22.0